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RELATIVE RESISTANCE OF VARIOUS HARDWOODS TO INJECTION WITH CREOSOTE.

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PURPOSE OF THE EXPERIMENTS.

When wood is impregnated with preservatives some species are more easily penetrated than others, so that for proper treatment the species should be grouped according to their relative resistance to injection. Otherwise, part of a cylinder charge might receive a heavy treatment and another part a very light one. As wood structure is the most important factor in the grouping of woods for treatment, the Forest Service has made a study to determine its influence upon penetration with creosote. Such factors as the amount and location of sapwood, the moisture content, and the like, encountered in the commercial treatment of wood, also have an important bearing

Note.—Acknowledgment is made to Miss Eloise Gerry, microscopist, Forest Products Laboratory, for the portions of this bulletin describing the structure of the broad-leaved trees, and for assistance in examining the specimens after treatment. Acknowledgment is also made to Mr. F. J. Angier, superintendent timber preservation, Baltimore & Ohio Railroad Co.; Dr. Irving W. Bailey, Harvard University; Mr. John Foley, forester, Pennsylvania Railroad Co.; Dr. Kendrick W. Hatt, professor of civil engineering, Purdue University; Mr. A. R. Joyce, of the Joyce-Watkins Co.; Mr. V. K. Hendricks, assistant chief engineer, and Mr. O. C. Steinmeyer, supervisor of timber preservation, St. Louis & San Francisco Railroad; and Mr. J. H. Waterman, superintendent timber preservation, Chicago, Burlington & Quincy Railroad, for their generous assistance in reviewing the bulletin.

on penetration, but were purposely eliminated from this study in order that the variables introduced by the structure of the wood could be studied independently. This point should be kept in mind when applying the results to the treatment of wood in commercial plants.

The experiments were made at the Forest Products Laboratory, maintained by the Forest Service, United States Department of Agriculture, in cooperation with the University of Wisconsin. The results should assist in establishing a basis for the grouping of species to secure the best treatment and the most efficient use of the preservative.

This bulletin is a study of the resistance to injection with creosote of some of the more important hardwood species native to this country. A similar study on coniferous woods was published in Bulletin 101 of the Department of Agriculture.

STRUCTURE OF THE HARDWOODS.

The term "hardwoods" as here used means those trees which have comparatively broad leaves and do not bear cones. The hardwoods (Angiosperms) differ in structure from the softwoods or conifers[1] (Gymnosperms) chiefly in the possession of *pores* or *vessels* (tracheae). For this reason the conifers are frequently called *non-porous* woods and the hardwoods either *diffuse-porous* or *ring-porous*, according to the arrangement of the pores or vessels in the annual ring. The different varieties of specialized cells and fibers and the arrangement of the cells in less uniform rows make the structure of the hardwoods much more complex than that of the conifers.

GROSS STRUCTURE.

Sapwood and heartwood.—The lighter-colored layer of wood on the outer circumference of the tree contains the living cells, and is known as the sapwood. In some species, such as aspen, the difference in color between sapwood and heartwood is hardly noticeable. As trees grow older the cell walls tend to become more and more infiltrated with various substances, which are often responsible for the color of the heartwood. During the change from sapwood to heartwood alterations sometimes occur in the pores, which, as a result, have a tendency in most species to become clogged or closed up.

Annual rings.—Each year the tree adds a fresh layer of wood substance under the bark around its circumference. These layers are called annual rings. The part which is formed early in the year is called springwood; that which grows later in the season, summer-

[1] For a description of the wood of the conifers see Bulletin 101 of the Department of Agriculture.

wood. These rings are more or less conspicuous in the hardwoods of temperate regions, especially in those of the ring-porous group. In general, the springwood is more open and has fewer thick-walled cells than the summerwood.

Medullary rays.—The medullary rays (silver grain) which extend like the spokes in a wheel from the bark toward the pith at the center of the tree, are very conspicuous in some hardwoods, such as oak, beech, and sycamore.

MICROSCOPIC STRUCTURE.

The microscopic structure of the hardwoods is illustrated by Plates I, II, III, and IV.

Plate I is a photograph, taken through the microscope, of a section of maple. This wood belongs to the diffuse-porous group of hardwoods, which is so called because the pores or vessels (V) are scattered with considerable uniformity throughout the annual ring (AR). In this group the pores in the springwood (SP) are generally but little larger than those in the summerwood (SW).

Plate II shows red oak, an example of ring-porous wood. In the springwood of this species there is a noticeable group of large pores. When seen on the cross-section of a log these make conspicuous concentric rings around the pith. In this wood the pores are not distributed uniformly through the annual ring and there is a very considerable difference in the sizes of those in the springwood and the summerwood. The springwood pores in a ring-porous wood are usually considerably larger than the corresponding pores in a diffuse-porous wood.

Although these two species are typical of the two groups, yet in each group it is possible to find variations from the types of structure shown. Some diffuse-porous woods, for example, are more porous than maple; that is, they have more pores per square inch in proportion to the number of fibers and the like than others do. Some of the ring-porous woods have the large springwood vessels blocked with cell-like growths called tyloses[1] (T, Plate IV). These are visible to the naked eye as glistening fragments in the pores of such woods as white oak or hickory. Tyloses are also present in the diffuse-porous woods, although somewhat less abundantly and uniformly developed. They occur in the vessels which are not active in the transfer of sap; therefore, they are most numerous and completely developed in the older sapwood and the heartwood.

Medullary rays.—The medullary rays (MR) are generally rather conspicuous in the hardwoods, although in woods like aspen and

[1] "Tyloses: Their occurrence and practical significance in some American woods," Journal of Agricultural Research, Vol. I, March, 1914.

willow they are narrow as compared with those in sycamore, beech, and oak.

Wood prosenchyma (Wood fibers, etc.)—Wood prosenchyma, (indicated by " X " in the plates, consists of thick-walled elongated cells in the form of fibers or of spindle-shaped cells with pointed, interlocking ends. These specialized cells give the mechanical strength required in the tree. In the softwoods the fibers, or tracheids, serve both for the conduction of liquids and for mechanical support. In the hardwoods, however, these two functions are separated. The pores or vessels act as a specialized conducting tissue, and the wood prosenchyma, though it shares in sap conduction to a small degree, acts chiefly as mechanical support.

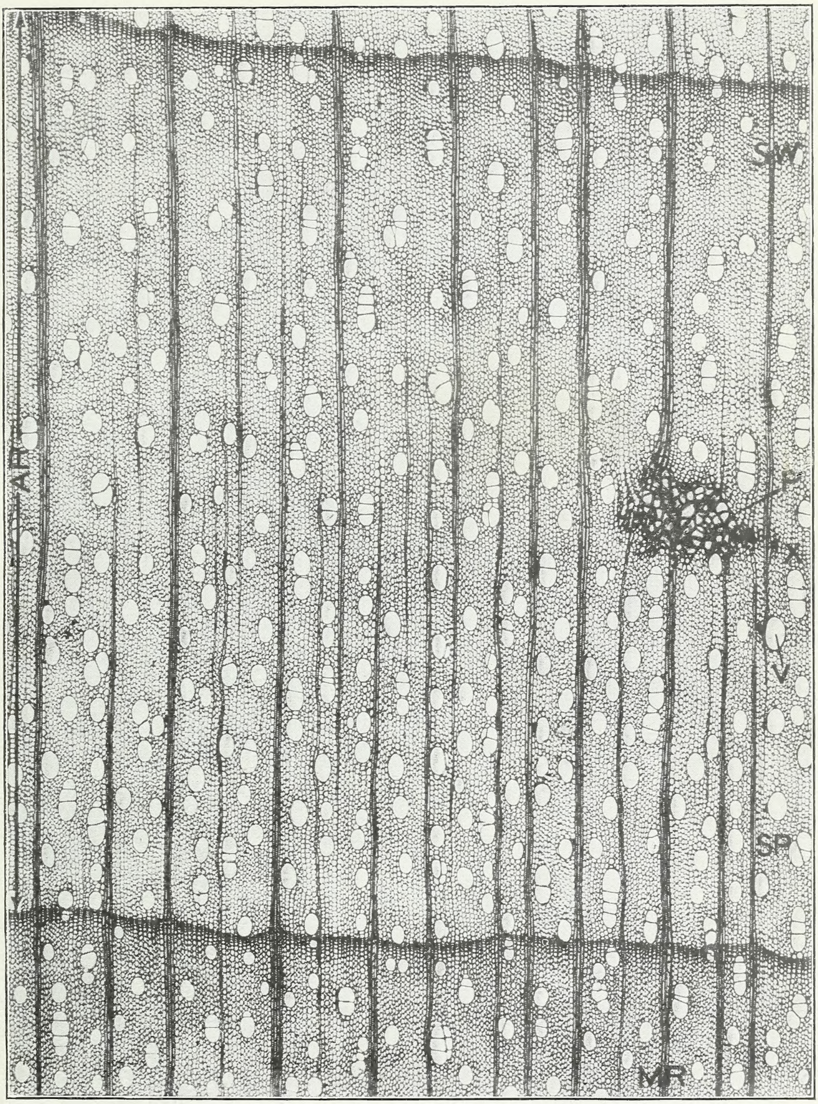
METHODS USED IN THE EXPERIMENTS.

The presence of large vessels, the extent to which these are blocked by tyloses and gums, and the presence of other infiltrating substances in the cell walls are known to be important factors in the impregnations of hardwoods with creosote. A very careful study was, therefore, made of these factors.

The resistance of the wood to treatment was studied in two kinds of tests: (1) Applying the creosote to a small area on a specimen and measuring the penetration in different directions, and (2) impregnation in a treating cylinder, blocks from each of the species being treated together in the same run. After treatment the specimens were examined under the microscope to determine the influence of the wood structure on penetration.

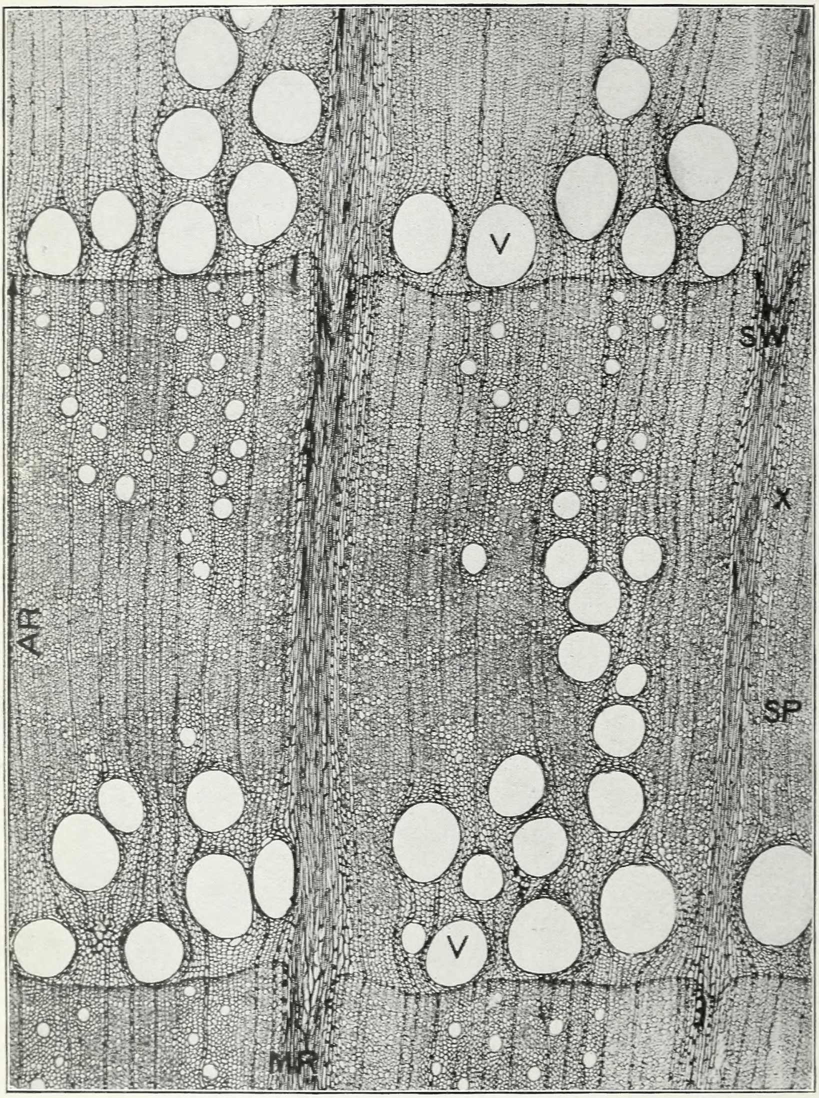
APPARATUS.

The penetrance apparatus in which the first series of tests was made is illustrated in figure 1. A hole three-fourths of an inch deep was bored in one face of the test specimen and the piece then clamped with the hole directly over the open end of pipe A, which led to the bottom of pressure tank B. The pipe and the lower portion of the tank were filled with creosote. Pressure was obtained by means of compressed air admitted through pipe C. A pressure regulator, K, was used to maintain a uniform pressure during the test. The apparatus was inclosed in a wooden oven having double glass windows in the front and back. Steam coils, J, heated the specimens and preservative to a constant temperature, which duplicated as nearly as possible the temperature conditions of a treating cylinder. Pressure and temperature were measured by gauge G and thermometer H. The specimens were placed on shelves in the apparatus and heated to a uniform temperature before testing. By the use of the



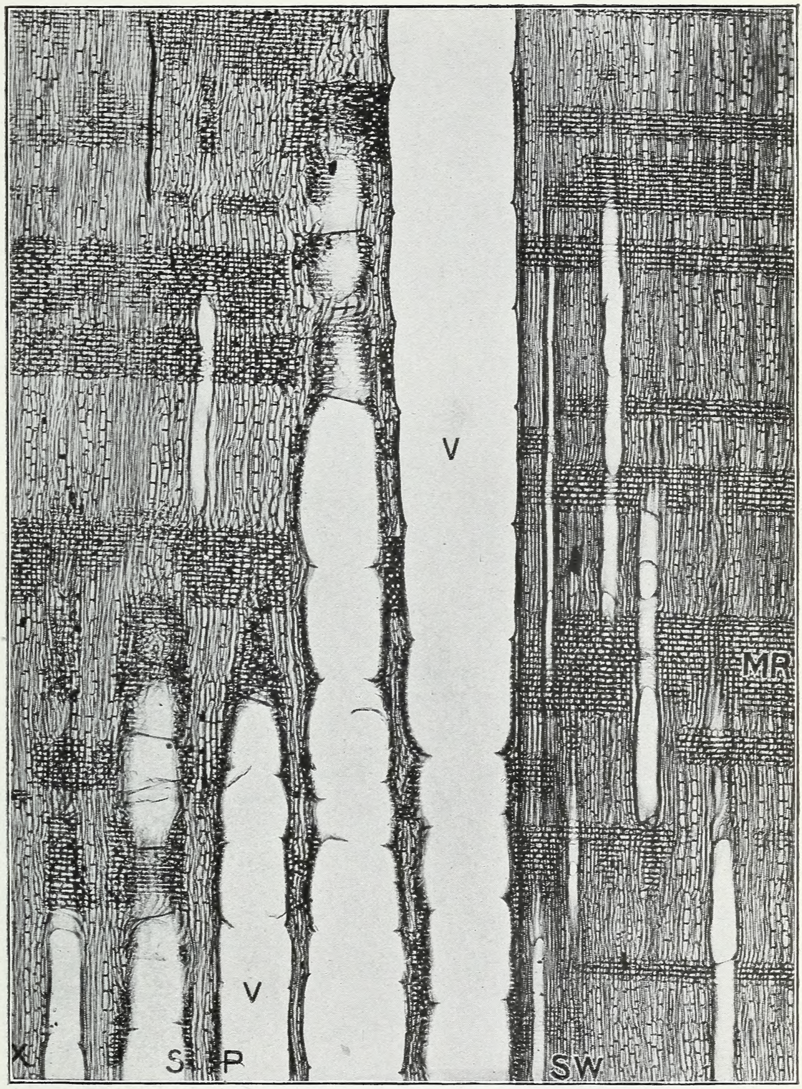
MAPLE (CROSS SECTION, MAGNIFIED 50 DIAMETERS). A DIFFUSE-POROUS WOOD.

AR, annual ring; *SP*, springwood; *SW*, summerwood; *MR*, medullary ray; *P*, pith fleck; *V*, pores or vessels; *X*, wood prosenchyma (fibers, etc.).



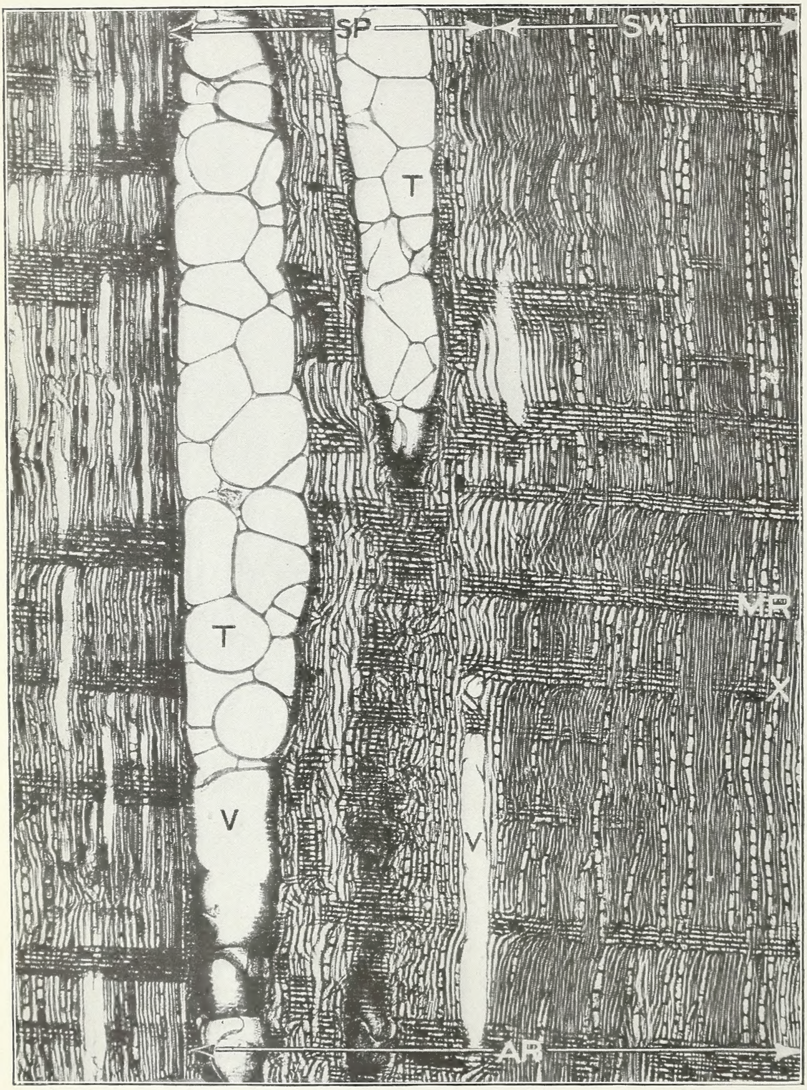
RED OAK (CROSS SECTION, MAGNIFIED 50 DIAMETERS). A RING-POROUS WOOD.

AR, annual ring; *SP*, springwood; *SW*, summerwood; *MR*, medullary ray; *V*, pores or vessels; *X*, wood prosenchyma (fibers, etc.).



RED OAK (RADIAL SECTION, MAGNIFIED 50 DIAMETERS).

SP, springwood; *SW*, summerwood; *MR*, medullary ray; *V*, pores or vessels; *X*, wood prosenchyma (fibers, etc.).



POST OAK, A WHITE OAK (RADIAL SECTION, MAGNIFIED 50 DIAMETERS).

SP, springwood; *SW*, summerwood; *MR*, medullary ray; *V*, pores or vessels; *X*, wood prosenchyma (fibers, etc.); *T*, tyloses.

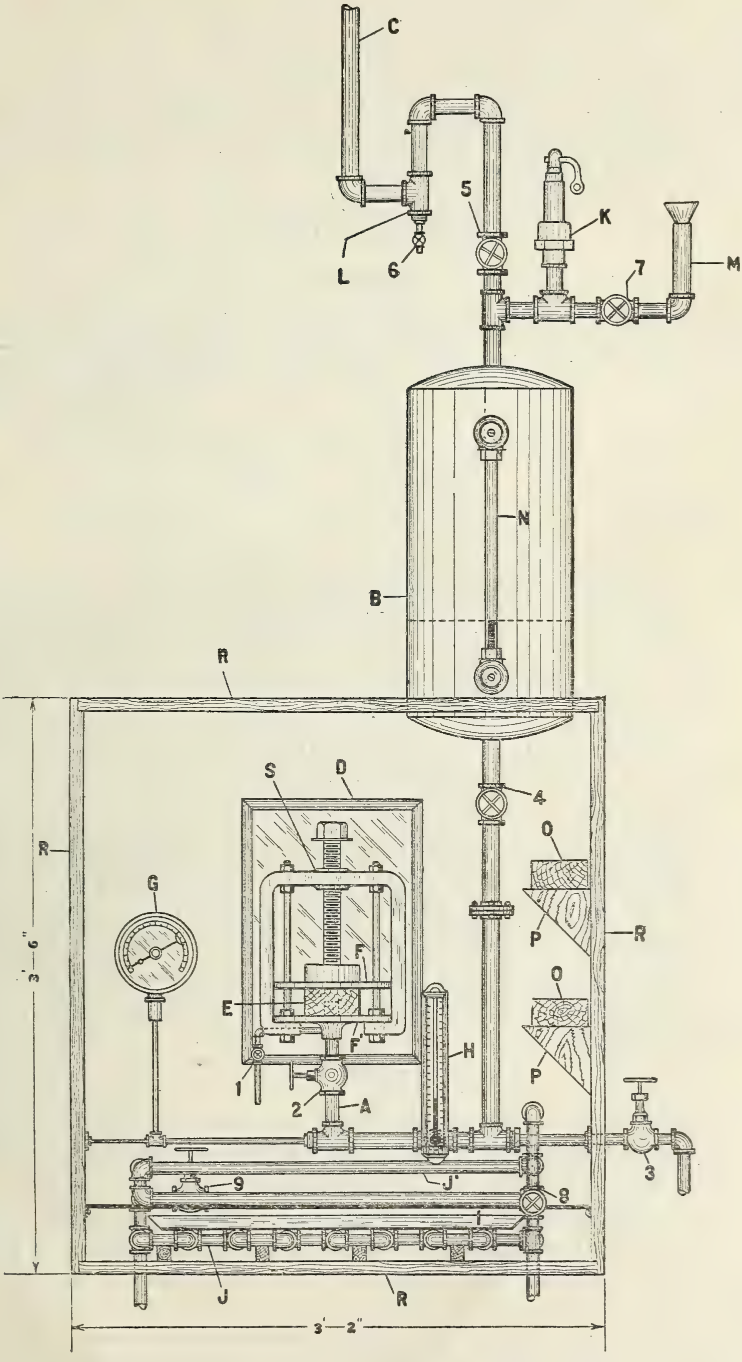


FIG. 1.—Apparatus for making penetrance tests.

mirror D, placed at the back of the oven, it was possible to observe both ends of the specimen during the test.

The impregnation tests were made in a cylinder 1½ feet in diameter and 4 feet long. Temperature and pressure were controlled by means of steam coils and a pressure pump. The specimens were separated from each other during treatment, so that all parts of the wood were in contact with the preservative.

MATERIALS USED.

CREOSOTE.

The creosote used was a coal-tar product with a specific gravity of 1.071 at 140° F. (60° C.) and a viscosity, determined by the Engler viscosimeter, of 1.2 at 160° F. (71° C.). The distillation[1] was as follows:

Temperature.	Distillation.
° *C.*	*Per cent.*
0–205	1.2
205–235	22.7
235–245	5.7
245–275	9.9
275–305	11.5
305–360	27.6
Residue	20.9
Loss	.5
Total	100.0

The creosote was obtained by distilling a by-product coke oven tar (Semet Solvay) to a very hard pitch. The indices of refraction at 60° C. and sulphonation tests are rather low for a pure coal-tar creosote, probably because the tar was produced in comparatively low-temperature ovens. The residue was a soft, sticky pitch, indicating the presence of a small amount of undistilled tar (probably less than 5 per cent).

WOOD.

The wood used in the experiments was selected from 25 species of hardwoods. In order to make the results comparable, all of the specimens for the different experiments on a given species were taken from the same log and matched as closely as possible. Most of the specimens used in the tests were heartwood, as sapwood specimens of sufficient size were available from only four of the species used.

[1] For method of analyses see Forest Service Circular 188, p. 36.

Three pieces of heartwood were selected from each species for the penetrance tests. Similarly, three specimens of sapwood were used of those species from which sapwood was available. The pieces were approximately $2\frac{1}{2}$ inches by $1\frac{1}{2}$ inches by 48 inches. Each specimen was surfaced on 4 sides, and a hole $\frac{3}{4}$ of an inch deep bored in the center of a $2\frac{1}{2}$ inch by 48 inch face. All specimens were first thoroughly air-seasoned, and then dried for 48 hours at a temperature of 150° F. before treatment. The oven-dry weight and moisture content were determined at the time of treatment.

Specimens used in the impregnation tests were cut approximately $2\frac{1}{2}$ inches by $1\frac{1}{2}$ inches by 24 inches. Seven selected specimens of heartwood from each species were treated. The same number of sapwood pieces of the species from which sapwood could be obtained were also treated.

The following species were tested:

Common name.	Botanical name.	Locality from which obtained.
Ash, green	*Fraxinus lanceolata* Borkh.	Missouri.
Ash, white	*Fraxinus americana* L.	New York.
Aspen, largetooth	*Populus grandidentata* Michx.	Wisconsin.
Basswood	*Tilia americana* L.	Do.
Beech [1]	*Fagus atropunicea* (Marsh.) Lud.	Pennsylvania.
Birch, river (red)	*Betula nigra* L.	(2)
Birch, sweet	*Betula lenta* L.	Pennsylvania.
Birch, yellow	*Betula lutea* Michx. f.	Do.
Cherry, wild red	*Prunus pennsylvanica* L.	Tennessee.
Chestnut	*Castanea dentata* (Marsh.) Borkh.	Do.
Elm, cork or rock	*Ulmus racemosa* Thomas	Pennsylvania.
Elm, slippery	*Ulmus pubescens* Walt.	Wisconsin.
Elm, white	*Ulmus americana* L.	Pennsylvania.
Gum, red	*Liquidambar styraciflua* L.	Missouri.
Gum, tupelo	*Nyssa, sp.*	Louisiana.
Hackberry	*Celtis occidentalis* L.	Wisconsin.
Hickory, mockernut	*Hicoria alba* (L.) Britt.	(2)
Maple, silver	*Acer saccharinum* L.	Wisconsin.
Maple, sugar	*Acer saccharum* Marsh.	Pennsylvania.
Oak, bur	*Quercus macrocarpa* Michx.	Wisconsin.
Oak, chestnut	*Quercus prinus* L.	Tennessee.
Oak, red	*Quercus rubra* L.	Pennsylvania.
Oak, white	*Quercus, alba* L.	Arkansas.
Sycamore	*Platanus occidentalis* L.	Tennessee.
Willow, black	*Salix nigra* Marsh.	Wisconsin.

[1] Red and white heart beech are botanically the same species.
[2] Obtained by purchase in the market. Locality of growth not known.

METHOD OF APPLYING THE CREOSOTE.

PENETRANCE TESTS.

In the penetrance tests a pressure of 120 pounds per square inch and a temperature of from 175° to 180° F. were employed. Readings of temperature and pressure were made every 15 minutes, and

the time was recorded at which the preservative first penetrated a surface. The periods of treatment were one-half hour, one hour, and two hours, respectively, for the three pieces from each species.

After treatment the specimens were sawed longitudinally and transversely along the center lines. (Fig. 2.) Immediately after sawing, the fresh surface was painted with water glass (sodium silicate solution) to prevent the creosote from staining the untreated surface. The longitudinal penetrations were measured on the surface obtained by sawing the specimens through the longitudinal center line. The average was obtained by measuring the area of the treated zone on this surface and dividing by the width of the penetration. The maximum and average radial and tangential penetrations were measured with a steel scale on the surface obtained by sawing the specimens transversely through the center line. These lines are indicated in figure 2; and Plates V to XII show specimens after being sawed. Radial and longitudinal penetrations were measured to the nearest 0.01 inch.

FIG. 2.—The general shape of the test pieces treated in the penetrance apparatus.

Photographs were taken of each specimen after treatment.

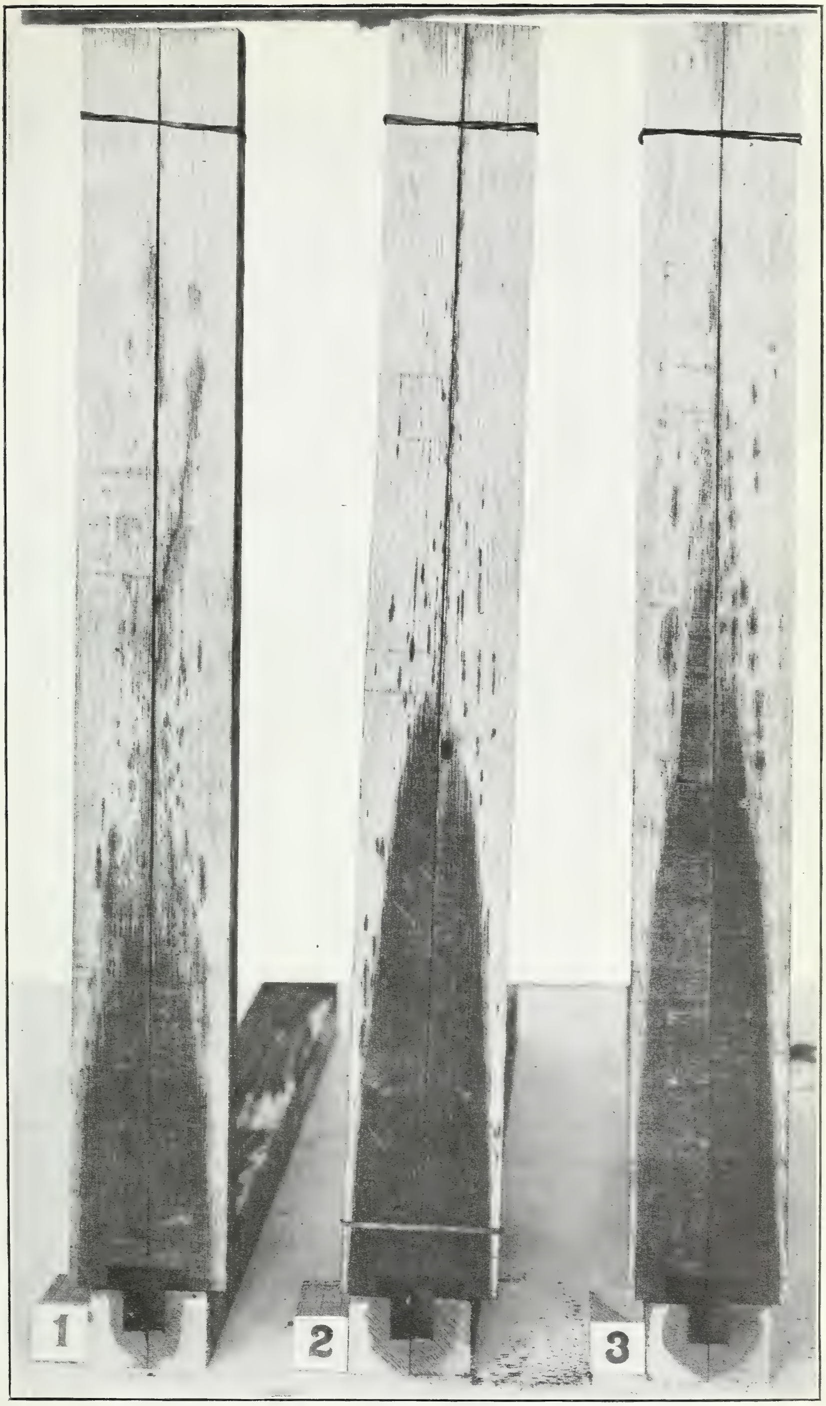
IMPREGNATION TESTS.

The impregnation tests comprised a series of seven treatments in which the pressure was varied and other conditions kept as nearly constant as possible. Each treatment was made on a heartwood specimen from each species. A sapwood specimen was also included from species having both sapwood and heartwood available.

The conditions of treatment are shown in Table 1.

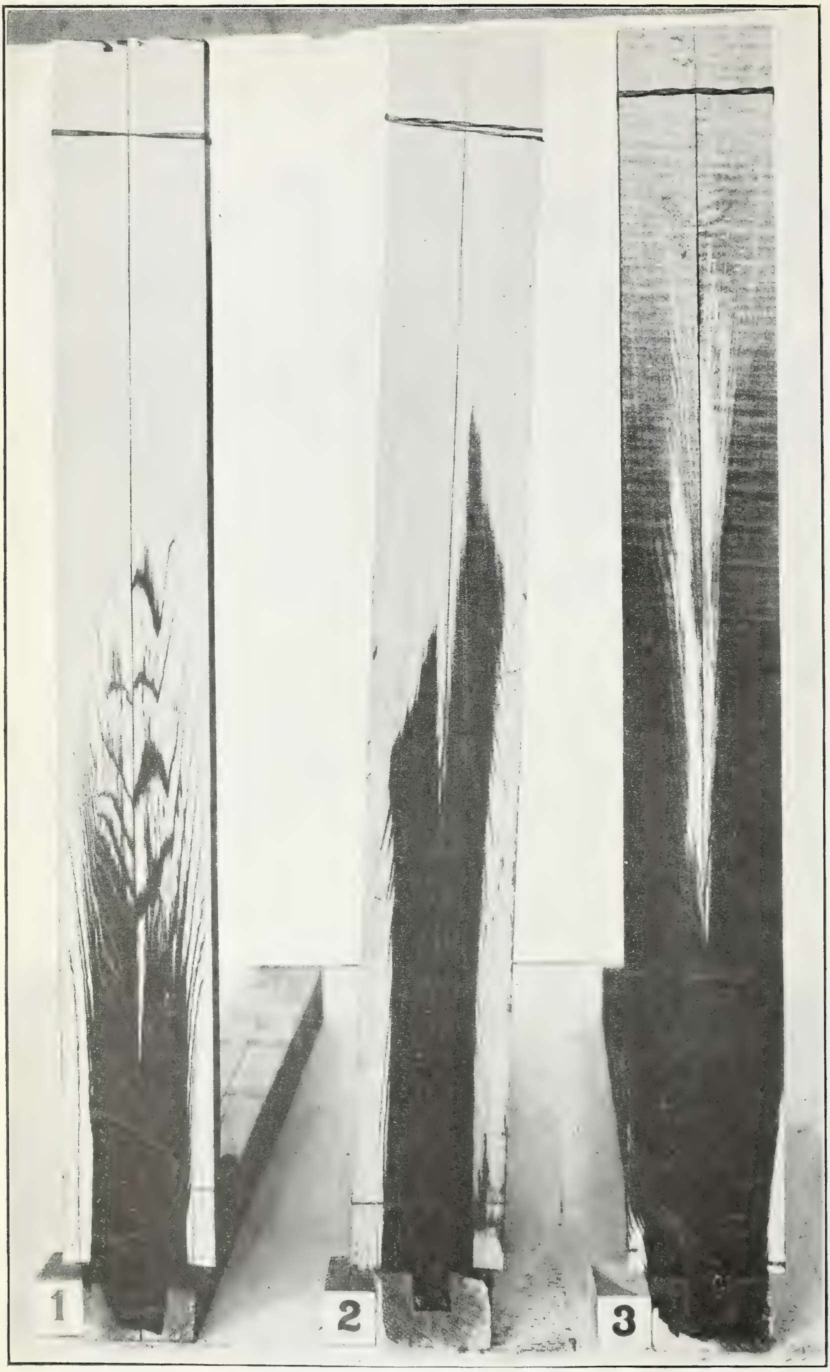
TABLE 1.—*The pressure, period, and temperature at which treatments were made.*

Run No.	Pressure.	Pressure period.	Temperature of preservative.
	Pounds per square inch.	*Hours.*	*°F.*
1	Atmospheric.	1	180–185
2	25	1	180–185
3	50	1	180–185
4	75	1	180–185
5	100	1	180–185
6	125	1	180–185
7	150	1	180–185



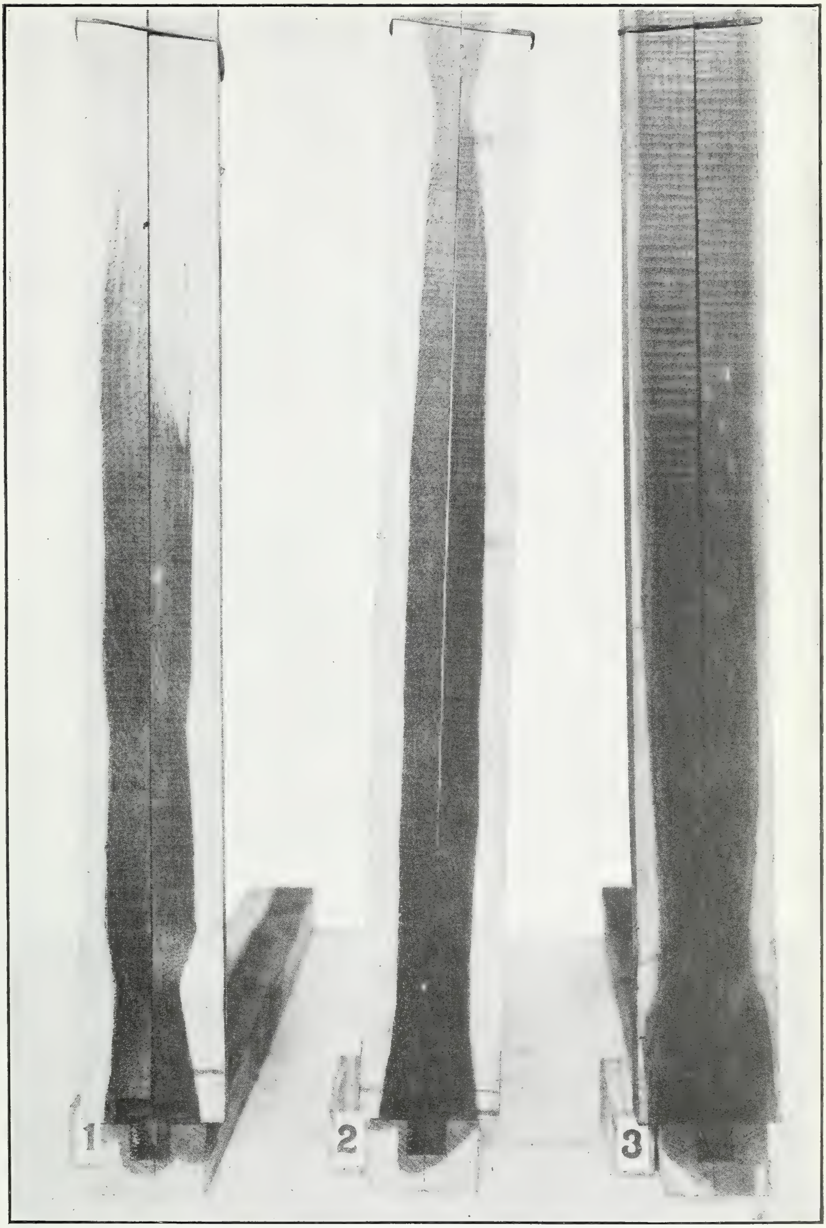
PENETRATION IN WHITE ASH—HEARTWOOD (FRAXINUS LANCEOLATA).

1, piece No. 66 treated 30 minutes; 2, piece No. 67 treated 60 minutes; 3, piece No. 68 treated 120 minutes. The thin-walled tyloses allowed the creosote to penetrate the vessels to some extent in addition to the penetration obtained in the wood prosenchyma. Spots on the untreated areas are points to which the creosote penetrated through the vessels.



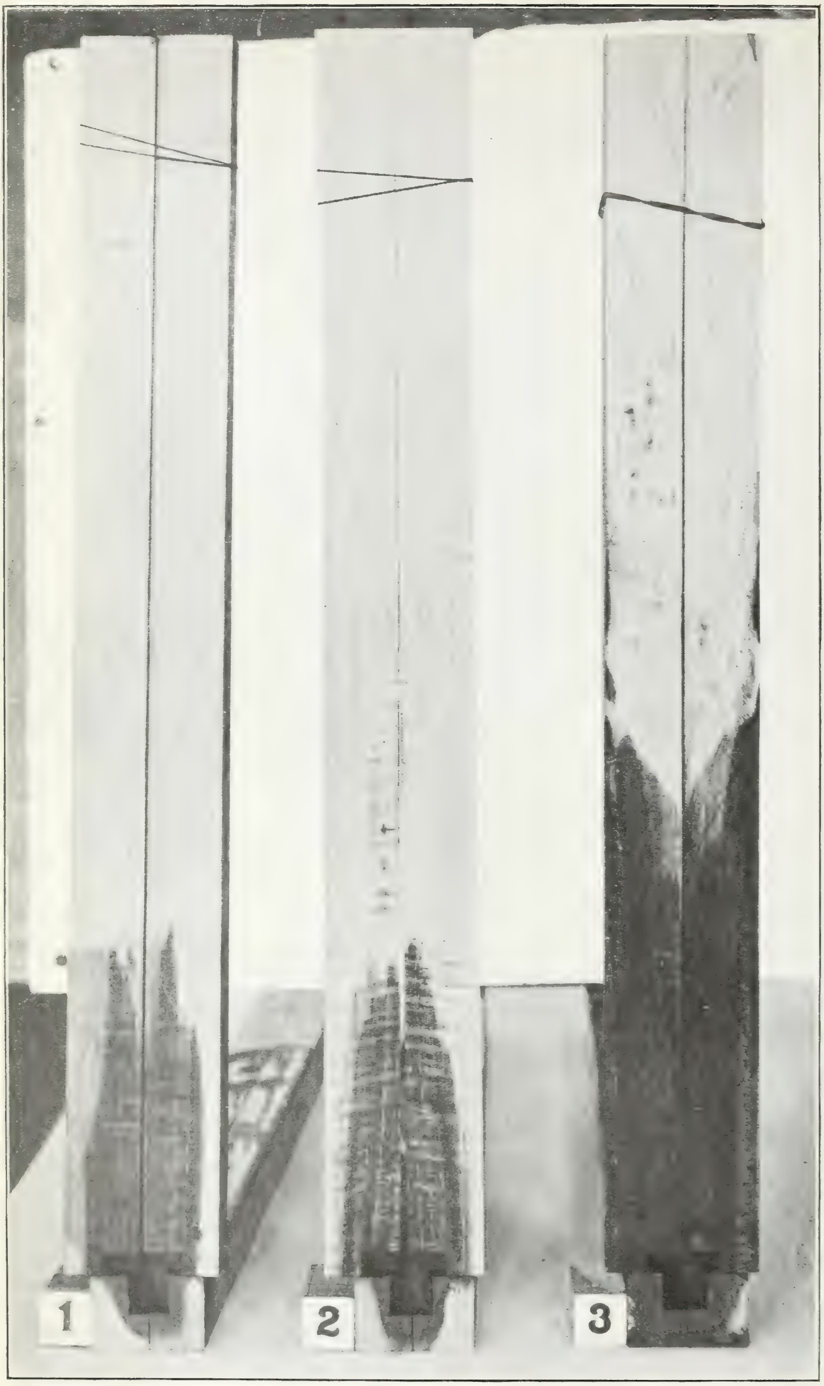
PENETRATION IN BASSWOOD—HEARTWOOD (TILIA AMERICANA).

1, piece No. 39 treated 30 minutes; 2, piece No. 40 treated 60 minutes; 3, piece No. 41 treated 120 minutes. Note the penetration of creosote in the summerwood first, in the piece on the left. Penetration took place readily in the summerwood because the wood prosenchyma is easily treated in this species.



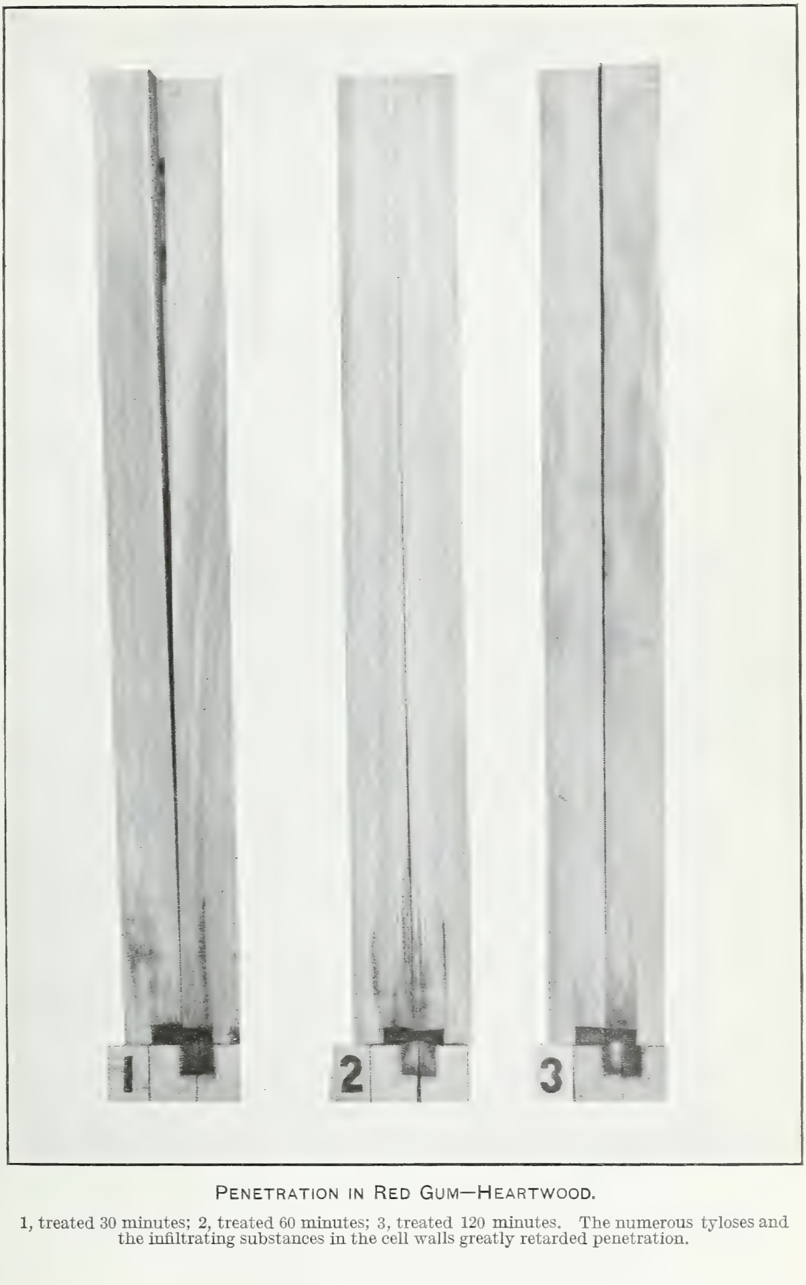
PENETRATION IN WHITE-HEART BEECH—HEARTWOOD (FAGUS ATROPUNICEA).

1, piece No. 86 treated 30 minutes; 2, piece No. 87 treated 60 minutes; 3, piece No. 88 treated 120 minutes. Compare the penetration of white-heart beech with that of red-heart beach, Plate XII.



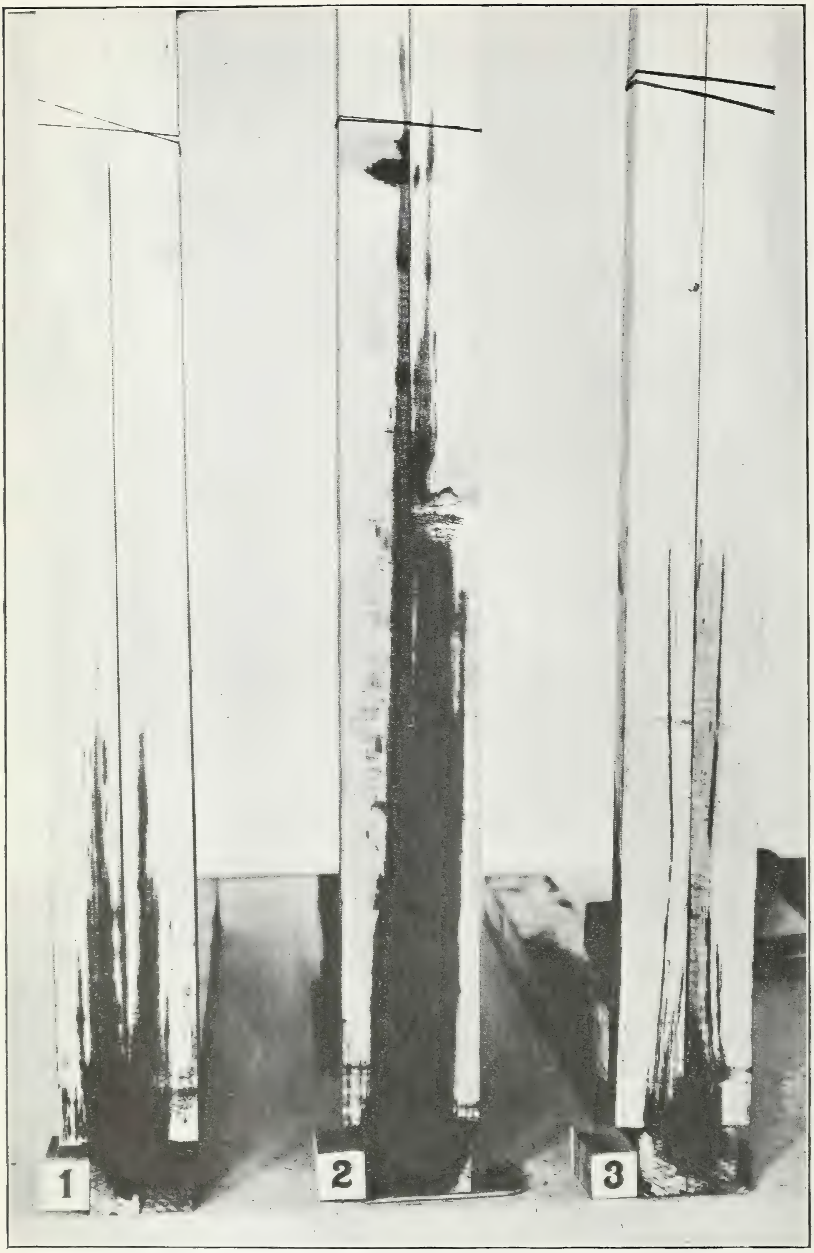
PENETRATION IN HICKORY HEARTWOOD (HICORIA ALBA).

1, piece No. 69 treated 30 minutes; 2, piece No. 70 treated 60 minutes; 3, piece No. 71 treated 120 minutes. Note the uniform penetration in wood even at a considerable distance from the part where creosote was applied.



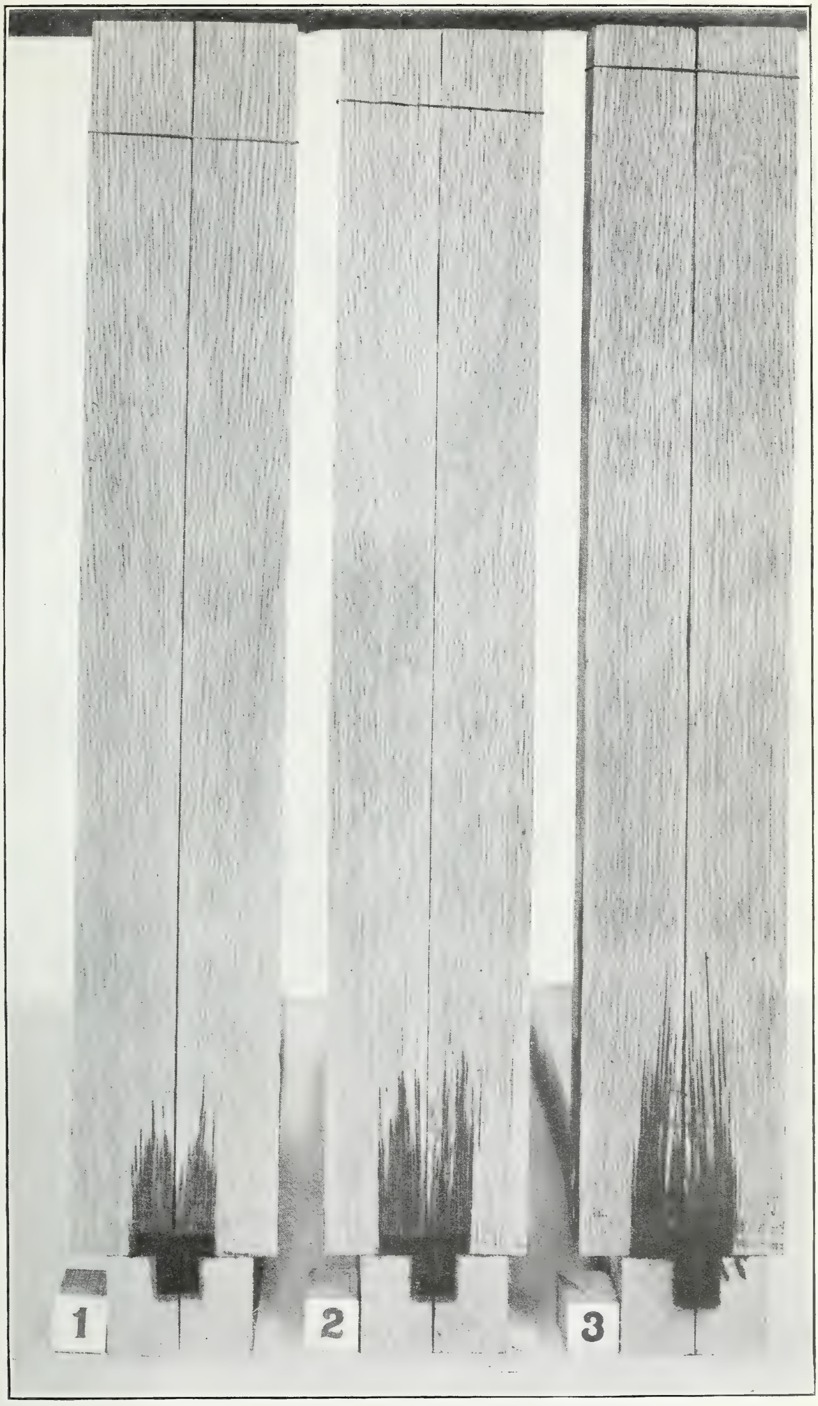
PENETRATION IN RED GUM—HEARTWOOD.

1, treated 30 minutes; 2, treated 60 minutes; 3, treated 120 minutes. The numerous tyloses and the infiltrating substances in the cell walls greatly retarded penetration.



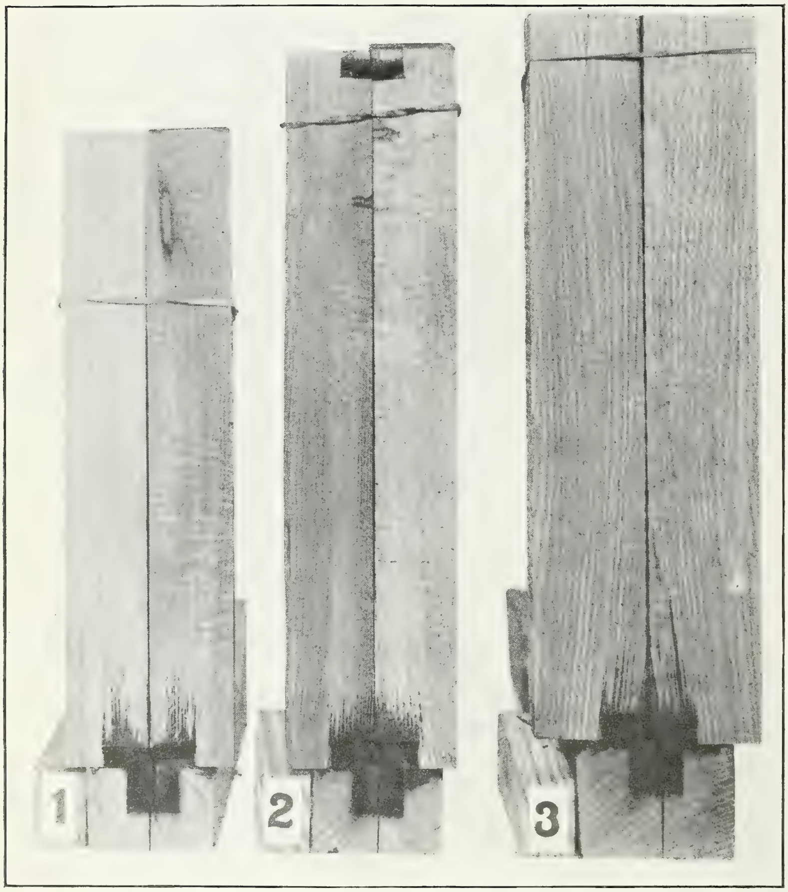
PENETRATION IN LARGETOOTH ASPEN—HEARTWOOD (POPULUS GRANDIDENTATA).

1, piece No. 45 treated 30 minutes; 2, piece No. 46 treated 60 minutes; 3, piece No. 47 treated 120 minutes. Largetooth aspen showed very erratic penetration, which is well illustrated in the three specimens shown.



PENETRATION IN WHITE OAK—HEARTWOOD (QUERCUS ALBA).

1, piece No. 77 treated 30 minutes; 2, piece No. 78 treated 60 minutes; 3, piece No. 79 treated 120 minutes.



PENETRATION IN RED-HEART BEECH (FAGUS ATROPUNICEA).

1, piece No. 89 treated 30 minutes; 2, piece No. 90 treated 60 minutes; 3, piece No. 91 treated 120 minutes. Compare the penetration in this wood with that shown in Plate VII, showing the penetration in white-heart beech.

FACTORS AFFECTING PENETRATION.

The penetrability of wood is greatly influenced by many factors not studied in these tests. Trees of the same species grown in different localities may differ greatly in their properties, hence the natural variability of the wood may largely influence penetration. The character of the penetration is an important factor. So also is the moisture content of the wood. Timber which has just been cut and which is, therefore, in the green condition is, as a rule, very much more resistant to treatment than that which has had the moisture removed. The method of seasoning the timber may also have an important bearing on the resulting penetration and absorption of preservative. Thus, wood which has been air seasoned may give quite different results from that which has been artificially seasoned either by steaming, boiling in oil, or by other processes.

In order to eliminate, so far as possible, variations arising from differences in moisture, the specimens used in the tests were dried to a low moisture content, although it is recognized that this is not done in commercial work where the methods of seasoning may vary greatly with different species of wood. Furthermore, sapwood and heartwood specimens were treated separately, although in commercial work timber under treatment may contain both heartwood and sapwood in widely varying proportions.

It was not within the scope of this work to study each species separately under the conditions most suitable for its treatment. The study was confined to one tree of each species. The trees were selected to be as nearly representative as possible, and all specimens used were closely matched. Since identical treatments were given to each species, it is possible to compare the penetrations and absorptions in the various species when tested under the same conditions.

EFFECT OF STRUCTURE ON PENETRANCE.

PORES OR VESSELS.

The pores or vessels, which serve to furnish a channel for the passage of sap from the roots of the tree to the leaves, are a very important factor in penetration with wood preservatives, especially when they are open passages through the wood.

1. Pores open.—In red oak, Plates II and III, the pores or vessels (V) are open passages. It is even possible to blow air through sticks of red oak several feet long. In a diffuse-porous wood they are more numerous but of smaller diameter. When the pores are open as in red oak or basswood, they are the main factor in the initial penetrance of the wood.

2. *Pores closed by tyloses or gums.*—When the pores or vessels are closed with tyloses, as in the post oak,[1] Plate IV, or with gummy substances, the relations are more complicated. Tyloses, if strongly developed, grow together and practically fill the vessel cavities, thus stopping the penetration through these elements. Creosote may be absorbed and stain the walls for a very short distance, but the main lines for liquid transfer are blocked. Various effects are produced by tyloses and gums according as these are more or less developed in different species. If the tyloses which grow out from different points on the walls of the pores or vessels do not meet and grow together, or if they are weak and readily broken down, they do not effectively check penetrance, as, for example, in chestnut and green ash. If they do not occur in all the vessels but only here and there, as in some diffuse-porous woods, their effect is, in general, proportional to their occurrence.

ARRANGEMENT OF THE PORES—RING-POROUS AND DIFFUSE-POROUS WOODS.

A much greater variation in penetration was found in the diffuse-porous than in the ring-porous species. In diffuse-porous woods tyloses were not so uniformly distributed, which resulted in erratic or irregular penetrations. Diffuse-porous woods also showed considerable variation, due to gums, infiltrating substances, and cross-grained structure. Examples of species exhibiting these variable characteristics are silver maple, sycamore, sugar maple, largetooth aspen, and red gum.

WOOD PROSENCHYMA (FIBERS AND TRACHEIDS).

When the pores or vessels of a wood are closed by tyloses or gums, penetration of the wood prosenchyma may become of primary importance. The cells of this tissue have closed ends. Liquids in passing from cell to cell must then filter through the wall itself or through the thin places or pits in the cell wall. The pits are poorly developed or practically lacking in some hardwood prosenchyma. It is therefore apparent that penetrance in this tissue can not take place so rapidly nor extend so easily for long distances as it can in the pores or vessels. (In Plates I, II, III, and IV this tissue is indicated by "X.") Nevertheless, the wood prosenchyma is of considerable importance in relation to the penetrance and absorption obtained for certain woods. Hickory is a particularly good example of a wood where penetrance takes place chiefly in the wood prosenchyma.

THE MEDULLARY RAYS AND WOOD PARENCHYMA.

The medullary rays and other parenchyma cells appeared to be of little practical importance in the penetration of the hardwoods with

[1] This species is similar in structure to white oak.

creosote. In oak, hickory, and sycamore, for example, the rays were conspicuous because of their resistance to penetration in marked contrast to the surrounding treated tissue.

SPRINGWOOD AND SUMMERWOOD.

In the hardwoods the effect of springwood or summerwood on treatment was not so important as the effect of the peculiarities of the different types of structure and the arrangement of the elements, such as vessels, fibers, rays, etc. In very heavy treatments the creosote not only passed through the cavities or lumena of the cells in both spring and summer wood, but sometimes penetrated the walls.

CONDITION OF GRAIN.

More or less difficulty was experienced in treating the woods in which the fibers were interlaced or cross-grained.

DENSITY.

The ease or difficulty of securing a satisfactory penetration does not appear to depend upon the density. Woods having high specific gravities were sometimes treated with greater ease than species of much lower specific gravity, and vice versa.

RADIAL, TANGENTIAL, AND LONGITUDINAL PENETRATION.

In most of the species tested the radial and tangential penetrations were very much less than the longitudinal penetration. In general, the species that were difficult to treat showed less difference than those which were easy to treat.

GROUPING OF SPECIES.

GROUPING WITH RESPECT TO PENETRATIONS AND ABSORPTIONS.

Table 2 (see Appendix) gives the average longitudinal and radial penetrations obtained in the penetrance tests, and the average absorptions of the specimens treated in the cylinder. In this table and in the diagram, figure 3, the species are arranged in order of increasing absorptions in the impregnation test. In figure 3 are also shown the corresponding average longitudinal and radial penetrations. While the longitudinal penetrations show a general tendency to increase as the absorptions increase, there is nevertheless a considerable variation. The radial penetrations were very small in most of the woods treated and do not seem to bear an important relation to the absorptions. In some cases it is possible that the longitudinal penetrations would have shown a closer relation to the absorptions if the average had been based on the same number of specimens in both series of tests. The penetrations represent the

average of three specimens of each species treated in the penetrance apparatus, and the absorptions are the average of seven specimens treated in the cylinder. However, a close relation between penetration and absorption could not be expected in many of the species. For example, species such as red oak and chestnut oak have large open pores or vessels which allow the preservative to pass easily from one end of the stick to the other. The wood prosenchyma of these species is very difficult to penetrate and treatment results mainly in coating the vessel walls with the preservative and not in

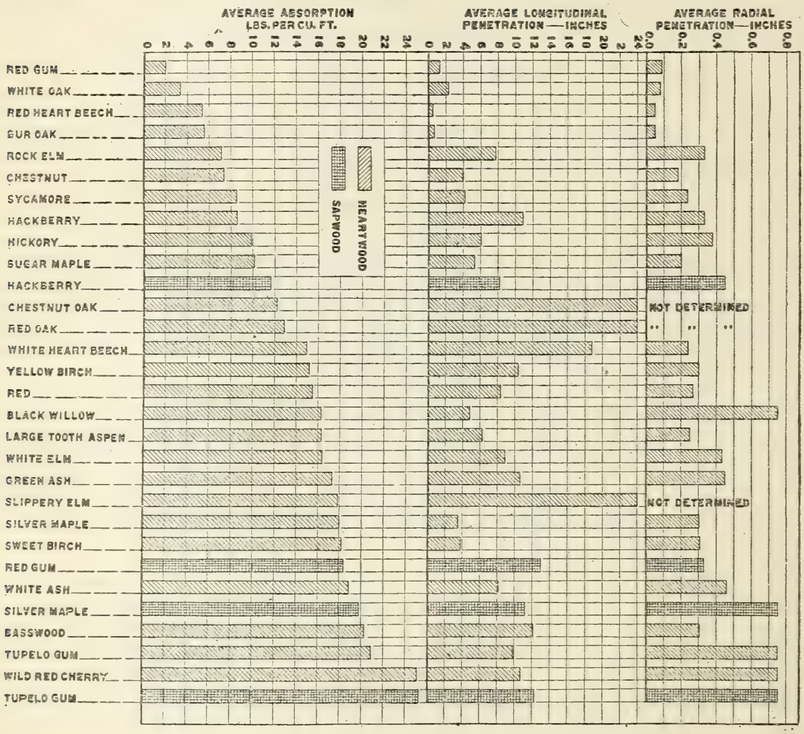


FIG. 3.—Comparative absorptions and penetrations.

a complete impregnation of the wood substance. Slippery elm has large open vessels similar to those of red oak and chestnut oak, but in this case the wood prosenchyma readily absorbs the preservative. It was therefore possible to secure both a complete penetration and a fairly heavy absorption in this wood. In hickory, the large vessels are almost completely closed by tyloses, but a fairly good penetration was obtained on account of the comparative ease with which the wood prosenchyma absorbed creosote. Species in which the tyloses are more or less irregularly distributed, such as black willow and large-

tooth aspen, naturally show less uniformity in the relation between penetration and absorption. A more constant relation between these factors is evident in species, such as basswood and tupelo gum, which take treatment both in vessels and in the wood substance.

Detailed results of the tests and data on each species are given in the Appendix.

GROUPING OF HARDWOODS FOR TREATMENT.

A classification of the species studied in this investigation into three groups according to the ease or difficulty of penetration has been attempted. This classification is based on the results obtained in the penetrance and cylinder tests and upon the structural characteristics as determined by a microscopic examination, and is intended only as an aid in the commercial grouping of such woods for treatment. The heartwood and sapwood are here considered separately, but in commercial treating plant operations the same stick often contains both; so the groups which are given may not be the ones which must be used in practice. For example, tupelo gum and red oak ties, both classed as easily treatable species, are not grouped together during treatment because the tupelo gum usually contains more sapwood.

Any grouping of species for preservative treatment must be a somewhat arbitrary classification. It is difficult to determine where the line should be drawn separating species of one group from those of another. However, when the classifications are taken as a whole there is a very distinct difference in the ease or difficulty with which the species of one group took treatment as compared with those of another group. Furthermore, the results obtained in the penetrance and absorption experiments correspond quite well in most cases with what would be expected from the structure of the various species. The grouping effected may be useful in giving an idea of what to expect of species unfamiliar to the reader, in comparison with species with which he is familiar.

GROUP I.

(Woods which treated easily in the tests.)

Ring-porous woods:

- Tyloses generally lacking—
  - Slippery elm — *Ulmus pubescens*, heartwood.
  - Red oak — *Quercus rubra*, heartwood.
  - Chestnut oak — *Quercus prinus*, heartwood.
- Tyloses scatteringly developed or thin walled—
  - White ash — *Fraxinus americana*, heartwood.
  - Green ash — *Fraxinus lanceolata*, heartwood.
  - White elm — *Ulmus americana*, heartwood.
  - Hackberry — *Celtis occidentalis*, sapwood.

Diffuse-porous woods:

Tyloses generally lacking—

Tupelo gum	*Nyssa sp.*, sapwood.
Wild red cherry	*Prunus pennsylvanica*, heartwood.
Tupelo gum	*Nyssa sp.*, heartwood.
Basswood	*Tilia americana*, heartwood.
Silver maple	*Acer saccharinum*, sapwood.

Tyloses scatteringly developed—

Red gum	*Liquidambar styraciflua*, sapwood.

Tyloses not present—

Yellow birch	*Betula lutea*, heartwood.
Sweet birch	*Betula lenta*, heartwood.
Red birch	*Betula nigra*, heartwood.
White-heart beech	*Fagus atropunicea*, heartwood.

GROUP II.

(Woods which were moderately difficult to treat in the tests.)

Ring-porous woods:

Tyloses present—

Mockernut[1] hickory	*Hicoria alba*, heartwood.
Hackberry	*Celtis occidentalis*, heartwood.
Rock elm	*Ulmus racemosa*, heartwood.
Chestnut	*Castanea dentata*, heartwood.

Diffuse-porous woods:

Tyloses present—

Black[2] willow	*Salix nigra*, heartwood.
Largetooth aspen	*Populus grandidentata*, heartwood.
Sycamore	*Platanus occidentalis*, heartwood.

Tyloses not present—

Sugar maple	*Acer saccharum*, heartwood.
Silver maple	*Acer saccharinum*, heartwood.

GROUP III.

(Woods which were very difficult to treat in the tests.)

Ring-porous woods:

Tyloses present—

Bur oak	*Quercus macrocarpa*, heartwood.
White oak	*Quercus alba*, heartwood.

Diffuse-porous woods:

Tyloses present—

Red-heart beech	*Fagus atropunicea*, heartwood.
Red gum	*Liquidambar styraciflua*, heartwood.

Group I.—All the specimens of Group I treated in the cylinder experiments were completely penetrated at 100 pounds pressure per square inch. An average absorption of more than 12 pounds per cubic foot was obtained in the cylinder treatment, and an average longitudinal penetration of over 8 inches was obtained in the penetrance experiments, with the exception of two species, hackberry, which received slightly less than 12 pounds of oil, and sweet birch, which received only 3.85 inches of longitudinal penetration. The low longitudinal penetration in sweet birch was due to crooked grain, the oil

[1] Hickory might be placed in Group I, as it showed good penetrations. The reason for placing it in Group II was that the absorptions were not so heavy as those obtained in the species given in Group I.

[2] Black willow specimens treated in the cylinder showed good absorptions and penetrations. Specimens treated in the penetrance apparatus did not show very extensive longitudinal penetration. This species is put in Group II rather than in Group I, as it is known to respond to treatment in a manner similar to large-tooth aspen, which in many cases is quite variable, partly on account of the irregular distribution of tyloses.

coming out at the side of the specimens instead of passing through to the end.

The pressure and time of treatment are not comparable to commercial treating-plant conditions because of the size and dry condition of the specimens.

The woods included in Group I were all comparatively free from tyloses and other obstructions in the vessels. Wood gums were present to only a slight extent; for example, in birch and maple. All of the species included in this group therefore treated very easily. Examples of species which exhibit very clearly the characteristic open structure are red oak, chestnut oak, and slippery elm. The wood prosenchyma, or fibrous part of the wood substance, was also usually well treated in woods of this group. The medullary rays and other parenchyma cells received, as a rule, little treatment, although exceptions were noted in woods like ash and birch where creosote also penetrated this part of the wood structure.

While numerous tyloses were found in the ashes, their influence on penetration of these species was not so important as in most of the other species in which tyloses were present. This was due to the fact that the tyloses were not fully developed in the vessels, and that they were also very often thin-walled and somewhat variable.

Group II.—With the exception of hickory, the species in Group II showed incomplete and variable penetrations in all of the cylinder treatments. The average absorptions obtained in these treatments were between 7 and 10 pounds per cubic foot in all of the species except silver maple, black willow, and largetooth aspen. In these three woods the absorptions were somewhat higher, but in the individual specimens they were extremely variable and the penetrations were very irregular on account of the uneven distribution of gummy substances in the maple and tyloses in the other two species. In all of the species of this group the average longitudinal penetrations obtained in the penetrance tests were between 4 and 8 inches.

Tyloses were present in all the species in this group except the two maples, but with few exceptions they did not completely close the vessels. Hickory was one of the few cases in which it was possible to obtain a fairly good penetration, although the pores were completely blocked with tyloses. In this species the treatment took place through the wood prosenchyma, which was quite permeable.

Group III.—The average absorptions in the cylinder experiments were less than 6 pounds per cubic foot, and the average longitudinal penetrations obtained in the penetrance tests were less than 2½ inches in all of the species classed in Group III. In most of these species the vessels were, as a rule, completely closed by an abundant growth of tyloses, which effectively retarded the entrance of creosote. The wood prosenchyma of these species was also very difficult to treat,

possibly because of the presence of infiltrated substances. The medullary rays were practically unpenetrated. Heartwood specimens treated in the cylinder rarely showed any more than a very slight end penetration.

RELATION OF GROUPING TO COMMERCIAL TREATMENT.

The form in which a timber is treated determines to a large extent the relative importance of securing a penetration in the sapwood or in the heartwood. Penetration of the sapwood is of principal importance in the treatment of material in round forms, such as posts and telephone poles, as in this case it is the sapwood that is exposed to the attack of fungi. Although tests could not be made on sapwood from each of the species used, the sapwood of practically all of these woods is known to be fairly easy to penetrate in both longitudinal and radial directions. Even those species which were most difficult to penetrate in the heartwood took treatment comparatively well in the sapwood.

In the treatment of sawed or split timbers, which generally have little or no sapwood, the penetration of the heartwood becomes of chief importance. The results of the experiments indicate that woods in Group I are well adapted for treatment in dimension form, since the heartwood as well as the sapwood of the species was penetrated with comparative ease. Where radial penetration of the heartwood is of special importance, as in the open-tank treatment of split timbers for fence posts, particular attention should be given to the ease or difficulty with which the wood prosenchyma can be penetrated.

The heartwood of some of the woods in Group II would probably be somewhat difficult to penetrate thoroughly and evenly in pressure treatments. This difficulty would be more apparent in the timbers of larger size, such as railroad ties, mine timbers, etc. With one or two exceptions, hickory, for example, radial penetration was small in species of this group. The heartwood of the species given in Group III would appear to be difficult to treat. Specimens of this group treated in the penetrance apparatus and in the cylinder showed no appreciable radial penetration, and only a slight longitudinal penetration at the ends.

CONCLUSIONS.

There are several very important factors other than the wood structure which, in commercial work, influence the absorption and penetration of preservative. Some of these are the natural variability of the wood, even in the same species, the moisture content when treated, the method of seasoning and treatment adopted, and the character of the preservative used. In order to study the true effects of the

various elements of wood structure on the penetration of creosote, it was necessary, so far as possible, to eliminate these other factors. The following conclusions, which are based only on structural considerations, should not be applied to commercial practice, such as the grouping of timber for treatment,[1] without considering the other factors that are involved.

1. The most important of the structural factors affecting the penetration of the hardwoods is the condition of the vessels in the wood. When the vessels are open, it is comparatively easy to secure a good penetration. If the vessels are closed by tyloses or gummy substances, they are usually rendered more or less impermeable to creosote.

2. Next in importance is the ability of the wood prosenchyma (fibers, etc.) to absorb creosote. In some species having numerous and well-developed tyloses in the pores (hickory, for example), it was found possible to obtain a deep penetration on account of the comparative ease with which the wood prosenchyma could be treated. The penetrability of this part of the wood structure is therefore of great importance in species having the vessels closed by tyloses or other material. The wood prosenchyma in the sapwood took treatment much more easily than that in the heartwood, probably because the heartwood contained infiltrating substances in the cell walls which tended to make the wood substance less permeable. Woods which were penetrated in both the vessels and wood prosenchyma generally showed the heavier absorption and deeper penetration. Those species which took very irregular absorptions in the cylinder tests were found to possess unusual structural characteristics, such as an irregular distribution of tyloses, interlaced fibers, or cross-grained structure.

The experiments indicate that even in species of very similar structure the manner of taking treatment may vary widely. This is illustrated in the treatment of hickory and white oak. Both of these woods are ring-porous and the vessels are closed by abundant tyloses. Hickory, however, took a fairly good treatment, whereas white oak was practically impermeable. The variation in the permeability of red heart and white heart beech is also an example of the different manner in which woods of similar structure may take treatment.

3. Penetration and absorption of the preservative is much less uniform in woods of the diffuse-porous group than in the ring-porous, probably because the tyloses in the vessels, and the gums and infiltrating substances are less uniformly distributed in diffuse-porous woods. In most of the species treated little or no penetration of the preservative occurred in the medullary rays and other parenchyma cells.

[1] Some of the other factors affecting the treatment of wood are taken up in Forest Service Bulletin 118, "Prolonging the Life of Crossties."

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APPENDIX.

CHARACTERISTICS OF THE VARIOUS SPECIES AND RESULTS OF TREATMENT.[1]

Ash, green (Fraxinus lanceolata)—heartwood.—Thin-walled tyloses were present in both sapwood and heartwood of green ash. Very little difficulty was experienced in obtaining a fairly good penetration in both the penetrance and cylinder treatments. Complete penetration resulted in the cylinder treatments when pressures of 75 pounds or more were employed. The wood prosenchyma was penetrated, and also the vessels and tyloses to some extent.

Ash, white (Fraxinus americana)—heartwood.—Thin-walled tyloses are scattered through both sapwood and heartwood of white ash. The wood took treatment fairly easily, good penetrations being obtained both in the penetrance and impregnation tests. Both the vessels containing tyloses and the wood prosenchyma were penetrated to some extent. Creosote was found distributed chiefly throughout the wood prosenchyma. Although this species has numerous tyloses, they are thin-walled. In all probability many of the vessels are not entirely closed by them, which allows the creosote to enter the pores and give fairly good penetrations.

Aspen, largetooth (Populus grandidentata)—heartwood.—Largetooth aspen is a close-grained, diffuse-porous wood with small pores. Both heartwood and sapwood contain scattered tyloses. Specimens treated in both the penetrance apparatus and in the cylinder showed quite variable penetrations. In all tests the penetrations were largely in streaks and in most cases entered the wood but a short distance. Some of the specimens were fairly well treated throughout their volume and others were only slightly penetrated. This variable penetration was very likely due to an unequal distribution of tyloses throughout the specimens, for the tyloses were found to be more numerous in the untreated portions. The preservative was found mainly in the vessels of the wood and to some extent in the prosenchyma.

Basswood (Tilia americana)—heartwood.—Basswood contains no tyloses in either the heartwood or sapwood. The specimens were easily treated in the penetrance apparatus and in the cylinder. Both the vessels and wood prosenchyma were quite thoroughly penetrated. Good penetrations were secured in the cylinder treatments, even at low pressures.

Beech, white-heart (Fagus atropunicea).—Tyloses are rarely found in either the heartwood or sapwood of white-heart beech. Creosote

[1] In some cases general remarks on the characteristics of the species were supplemented from the descriptions given in Snow's "Principal Species of Woods."

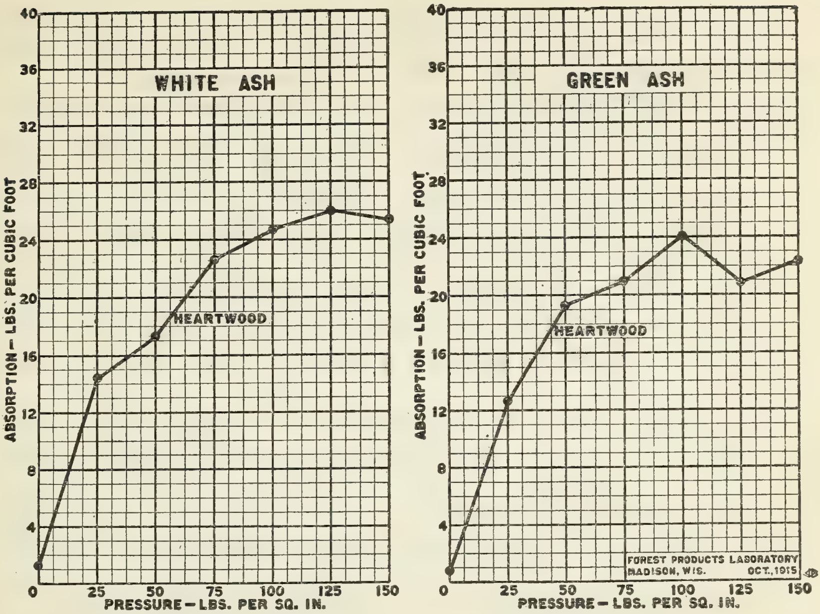

Fig. 4.—Absorption in the heartwood of white ash and green ash.

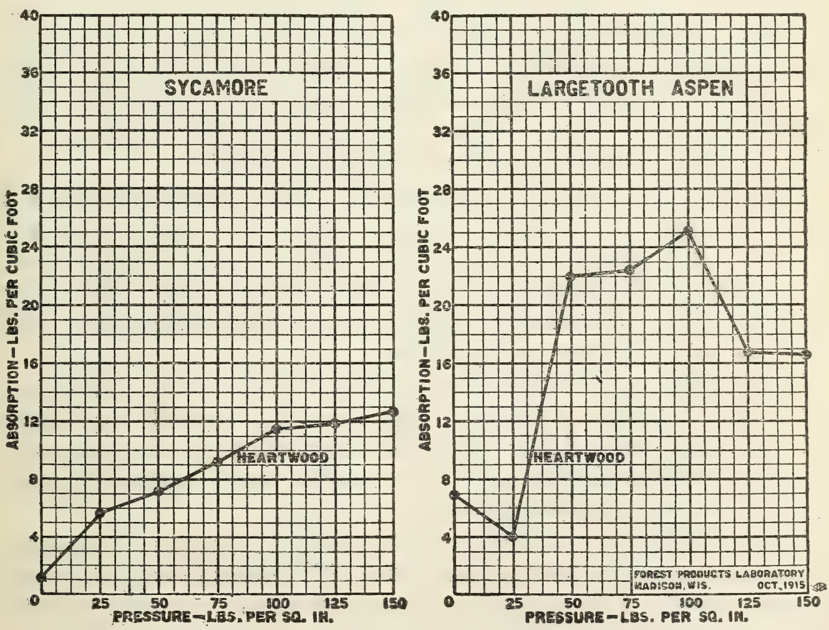

Fig. 5.—Absorption in the heartwood of sycamore and largetooth aspen.

penetrated the wood very readily both in the penetrance and cylinder treatments. The penetrance was especially uniform in this species and the oil apparently reached all parts of the wood structure.

Beech, red-heart (*Fagus atropunicea*).—Red-heart beech contains numerous tyloses in the heartwood and few in the sapwood. This wood was found to be very difficult to penetrate. Specimens treated in the cylinder showed only a very limited end penetration. A very small amount of creosote was found in the vessels and little or none in the wood prosenchyma. The difficulty of penetration seems to have been caused by the abundant tyloses found in the pores of the wood and by the infiltrating substances in the fiber walls of the "red heart" portion, which apparently prevented penetration in these elements.

Birch, sweet (*Betula lenta*)—*heartwood.*—The fibers in sweet birch are thick-walled, and gummy substances are frequently found in the wood. Tyloses are not found in either sapwood or heartwood. Specimens treated in the cylinder were well penetrated even at low pressures. Penetration was found to be well distributed throughout the wood structure. The wood prosenchyma was fairly well penetrated, but creosote was present to a greater extent in the vessels.

Birch, yellow (*Betula lutea*)—*heartwood.*—Yellow birch contains no tyloses in either sapwood or heartwood. The pores were very easily penetrated in all of the tests. In the penetrance tests the preservative penetrated to the ends of the sticks almost immediately after pressure was applied. In the cylinder treatments the vessels were easily penetrated when the wood was merely immersed in the preservative for an hour. When pressure was applied both the vessels and wood prosenchyma were thoroughly treated.

Birch, red (*Betula nigra*)—*heartwood.*—The pores in red birch are somewhat larger than those in sweet birch. The wood fibers are fairly thin-walled and there are no tyloses in sapwood or heartwood. As in yellow birch, the vessels were rather easily penetrated at low pressures. At pressures of 50 pounds or more both the vessels and wood prosenchyma were well penetrated.

Cherry, wild red (*Prunus pennsylvanica*)—*heartwood.*—Wild red cherry does not contain tyloses. The wood was treated very easily and was found to be fairly well penetrated when merely immersed in the preservative for an hour. Penetration was complete in practically all of the treatments made.

Chestnut (*Castanea dentata*)—*heartwood.*—The pores in chestnut are numerous and are more or less filled with tyloses in both sapwood and heartwood. This species was very difficult to penetrate both in the penetrance apparatus and in the cylinder. Specimens treated in the cylinder showed very little radial or tangential penetration. The tyloses appeared to close the vessels, so that only a very limited pene-

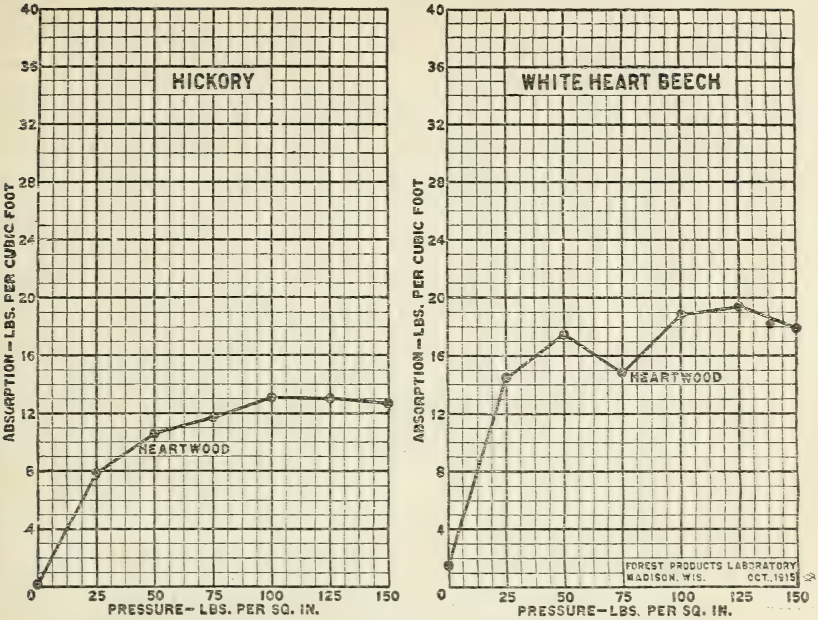

Fig. 6.—Absorption in the heartwood of hickory and white-heart beech.

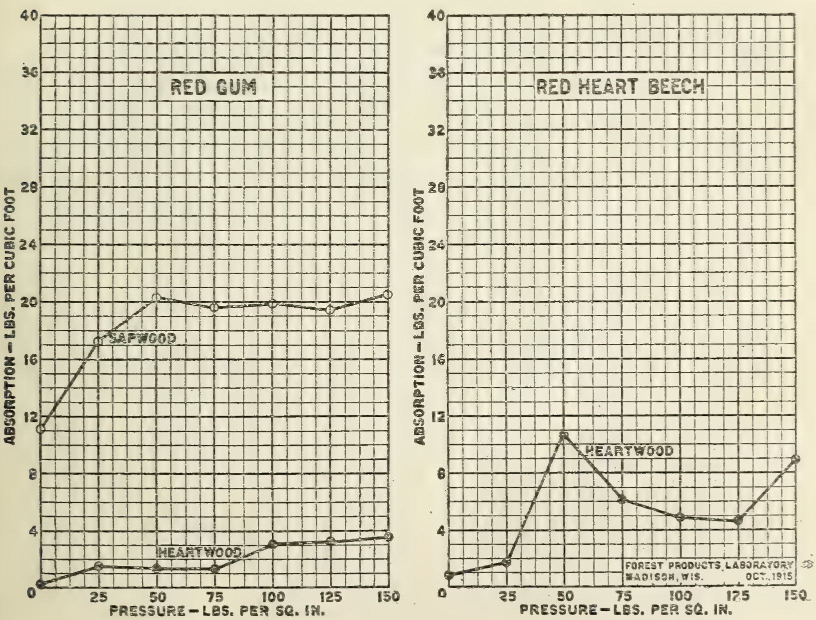

Fig. 7.—Absorption in the heartwood of red gum and red-heart beech and the sapwood of red gum.

tration could be obtained at any of the pressures used. Creosote was found chiefly in the vessels and very little in the wood prosenchyma or medullary rays.

Elm, rock (*Ulmus racemosa*)—*heartwood.*—Rock elm is a ring-porous wood with interlaced fibers. Tyloses were generally few and scattered in the specimens treated. All of the specimens tested in both the penetrance apparatus and in the cylinder showed erratic penetrations. In most cases penetration took place in streaks, some of the wood being well penetrated and other parts entirely untouched. Specimens treated in the cylinder at the lower pressures showed a better absorption and penetration than specimens treated at the higher pressures. This may have been due to an irregular distribution of tyloses in the specimens. The difficulty with which this wood takes treatment seems to indicate that the interlaced condition of the wood fibers may vary throughout the stick, thereby causing irregular penetrations. Most of the preservative was found to be in the vessels. There was very slight penetration in the wood prosenchyma and medullary rays.

Elm, slippery (*Ulmus pubescens*)—*heartwood.*—There are practically no tyloses present in either sapwood or heartwood of slippery elm. On account of the open condition of the large and numerous pores, it was not possible to make any tests in the penetrance apparatus. The creosote penetrated the wood largely through the vessels, but also to some extent in the wood prosenchyma. Good penetrations were easily secured on account of the large open pores.

Elm, white (*Ulmus americana*)—*heartwood.*—Tyloses were few and scattered in the specimens of white elm tested, and the penetration was chiefly in the vessels. The medullary rays and wood prosenchyma had only a slight penetration. Specimens treated in the cylinder showed good penetrations with most of the pressures employed. Fairly good penetrations were also secured in the penetrance apparatus.

Gum, red (*Liquidambar styraciflua*)—*heartwood and sapwood.*—Red gum is rather heavy, moderately hard, and cross-grained. The fibers generally have thick walls and are arranged in definite radial rows. The species is diffuse-porous with pores numerous and uniformly distributed. Tyloses are usually present and scattered in both heartwood and sapwood. Infiltrating substances are present to a large extent in the cell walls. It was difficult to secure an appreciable penetration of the heartwood in any of the treatments. Specimens treated in the cylinder showed practically no radial or tangential penetration. The difficulty in treating this wood was very likely due in a large degree to the infiltrating substances in the cell walls, as well as tyloses, which prevented the preservative from entering the vessels in which they were well developed. The cross-grained structure and thick walls of the fibers may also have been factors influenc-

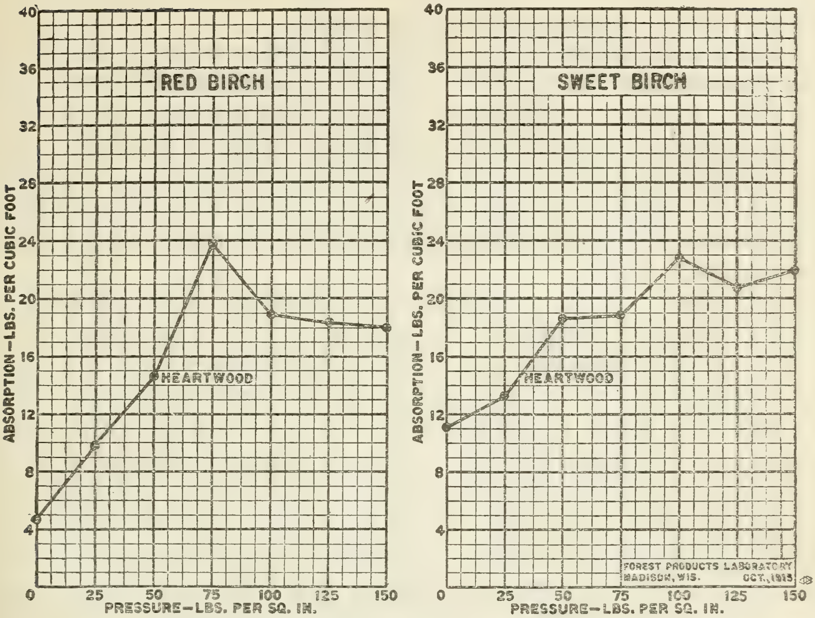

FIG. 8.—Absorption in the heartwood of red birch and sweet birch.

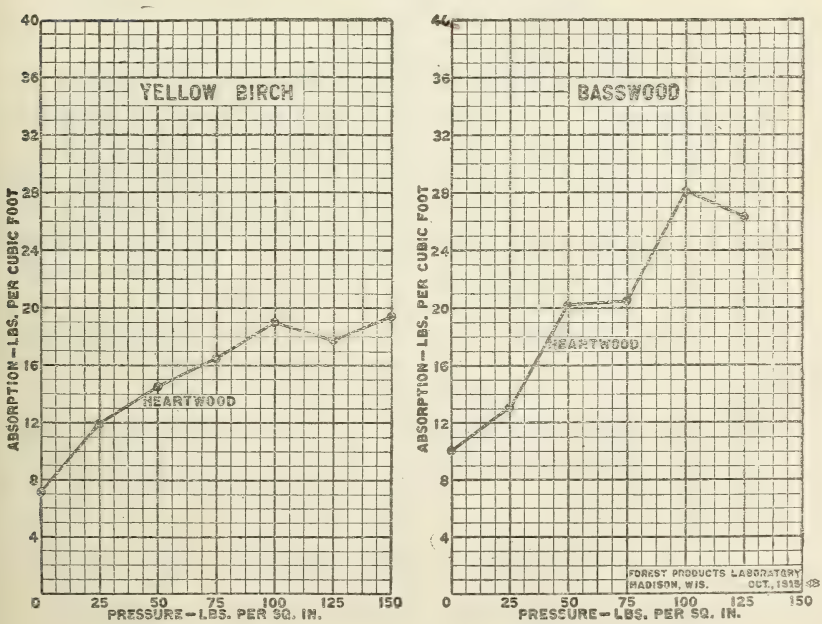

FIG. 9.—Absorption in the heartwood of yellow birch and basswood.

ing the absorption and penetration to some extent. The sapwood was very easily treated even at low pressures.

Gum, tupelo (Nyssa, sp.)—heartwood and sapwood.—In tupelo gum the pores are numerous, of medium size, and usually evenly distributed. No tyloses were found in the species treated. On account of the numerous vessels and penetrable structure of the fiber walls, good penetrations were obtained. Both the heartwood and sapwood treated very easily even at low pressure. Sapwood specimens were well penetrated when immersed for an hour in the preservative without pressure.

Hackberry (Celtis occidentalis)—heartwood and sapwood.—Tyloses occurred irregularly in both heartwood and sapwood of hackberry. The penetration occurred mainly in the vessels and wood prosenchyma and to a small extent in the medullary rays. The sapwood was fairly easily penetrated even at low pressures, particularly in the summerwood. With the higher pressures used in the cylinder treatments, both springwood and summerwood were well penetrated. The heartwood showed an irregular penetration in all of the cylinder treatments, due, in part, to the abundant tyloses in the vessels of the untreated portions. The springwood was found to be much more difficult to treat than the summerwood because many well developed tyloses closed the large springwood vessels.

Hickory, mockernut (Hicoria alba)—heartwood.—Hickory is a ring-porous wood, in which the fibers are relatively thick-walled and tyloses are generally abundant in both sapwood and heartwood. All the specimens showed a fairly uniform penetration, and those treated in the cylinder were well penetrated when pressures of 50 pounds or more were employed. Creosote was found to have penetrated mainly in the wood prosenchyma, and there was little or no penetration in the vessels or in the medullary rays. It is probable that the abundance of tyloses in the vessels effectively closed them against the entrance of the preservative. Penetration in this species would, therefore, seem to be dependent on the ease with which the wood prosenchyma can be treated. In even the most thoroughly penetrated specimens the tyloses remain uncolored, indicating that in this wood these growths were practically impermeable to creosote.

Maple, silver (Acer saccharinum)—heartwood and sapwood.—Silver maple is a diffuse-porous wood. No tyloses were present in the specimens treated. Both the sapwood and heartwood were found to be fairly easy to treat, but more variation in penetration was found in the heartwood specimens. At low pressures the heartwood showed a mottled or streaked appearance, probably due to the presence of gums. A good penetration was secured in the sapwood at pressures over 25 pounds per square inch. Penetration took place mainly in the vessels and wood prosenchyma and was very slight in the medullary rays.

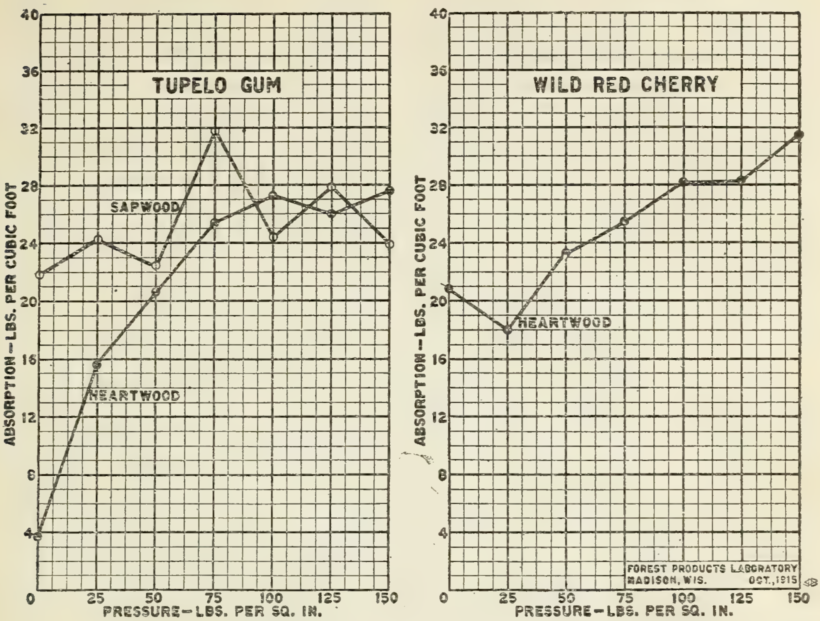

FIG. 10.—Absorption in the heartwood of wild red cherry and in the heartwood and sapwood of tupelo gum.

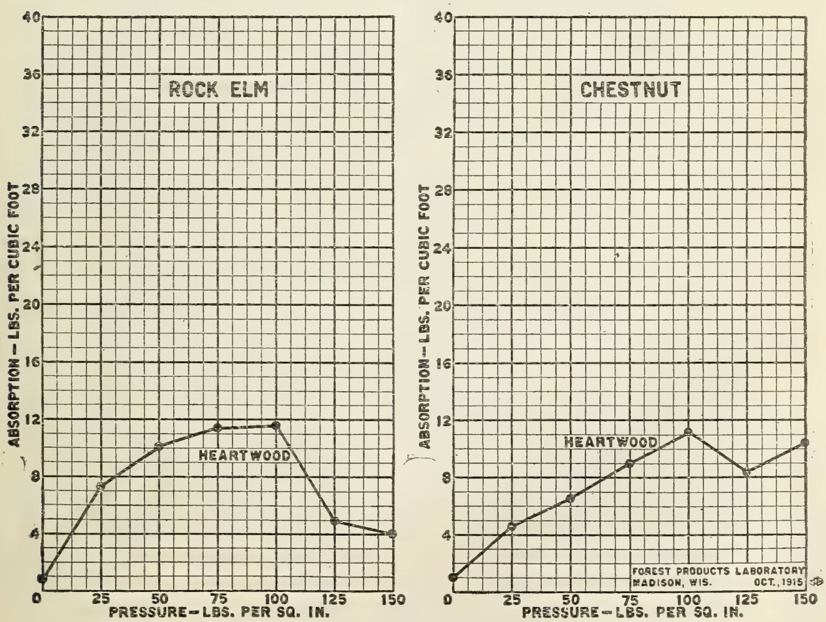

FIG. 11.—Absorption in the heartwood of rock elm and chestnut.

Maple, sugar (*Acer saccharum*)—*heartwood.*—Sugar maple is a diffuse-porous wood. In the specimens tested tyloses were not present in either sapwood or heartwood, but gums and infiltrating substances were present. The specimens showed a more or less variable penetration. In the cylinder treatments some of the pieces were well penetrated and others were penetrated but a short distance or in streaks. Creosote penetrated chiefly in the wood prosenchyma, although it was also present to some extent in the vessels. The presence of gums seems to be responsible for the variable penetrations secured in the tests.

Oak, bur (*Quercus macrocarpa*).—Tyloses are numerous in both sapwood and heartwood of bur oak. The effect of tyloses on penetration is very marked in this species, and it was found to be almost impossible to penetrate the heartwood to an appreciable extent. Very little creosote was found in the vessels, which seemed to be effectively blocked by tyloses. Two or three of the specimens treated in the cylinder showed a fairly good penetration in part of the wood. The distinct demarcation of the treated and untreated areas seemed to indicate that the wood which was penetrated might have been sapwood not clearly distinguishable before treatment. The medullary rays were practically untreated in all of the tests.

Oak, chestnut (*Quercus prinus*)—*heartwood.*—The structure of chestnut oak is very similar to that of red oak, being ring-porous and generally without tyloses, although botanically chestnut oak is classed as a white oak. Penetrance tests could not be made on this species on account of the open condition of the vessels. Penetration took place mainly in the vessels or pores. The cell walls were practically unpenetrated by the preservative. Railroads have frequently classed this species with the white oaks and installed chestnut oak ties in the track without treatment. Since the wood takes treatment easily and the pores generally are without tyloses, chestnut oak ties should evidently be treated with a preservative.

Oak, red (*Quercus rubra*)—*heartwood.*—There are practically no tyloses in the vessels of red oak. On account of the very porous condition of the wood, penetrance tests could not be made. Specimens treated in the cylinder were penetrated largely in the vessels, but very little in the heartwood prosenchyma. The sapwood prosenchyma, however, is known to take treatment very easily.

Oak, white (*Quercus alba*)—*heartwood.*—The pores in both sapwood and heartwood of white oak are filled with tyloses. These tyloses and the character of the wood prosenchyma were an important factor in making it difficult to secure more than a very slight penetration in the specimens tested. Very little creosote was found in either the vessels or wood prosenchyma. The tyloses were found to be unpenetrated even in those portions of the wood which had been treated.

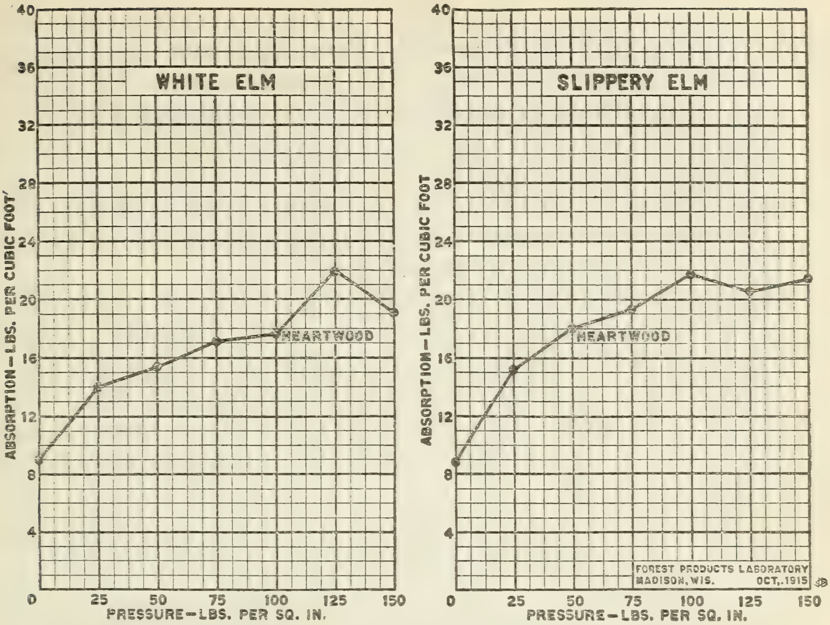

Fig. 12.—Absorption in the heartwood of white elm and slippery elm.

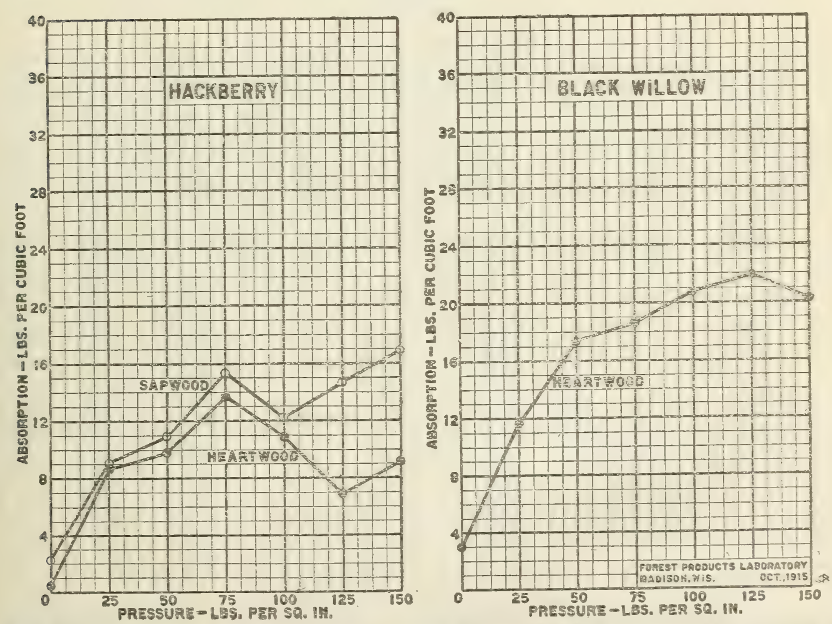

Fig. 13.—Absorption in the heartwood of hackberry and black willow and the sapwood of hackberry.

Sycamore (*Platanus occidentalis*).—Tyloses occurred scatteringly in the specimens of sycamore treated. Penetration was found to take place mainly through the vessels. Very little creosote was found in the wood prosenchyma or parenchyma. The wood was difficult to treat in either the penetrance apparatus or in the cylinder. Complete penetrations in the impregnation tests were not obtained, even at pressures of from 125 to 150 pounds per square inch. The difficulty in treating this species seems to be due largely to the tyloses and to the cross-grained structure of the wood.

Willow, black (*Salix nigra*)—*heartwood*.—Knots in the wood made it difficult to get good clear specimens of willow. Specimens treated in the cylinder showed fairly good penetrations for most of the pressures used. Tyloses are scattered in both sapwood and heartwood. The tyloses in the vessels did not prevent penetration. Creosote was found to be present to a considerable extent in both the vessels and the wood prosenchyma.

TABLE 2.—*Species in the order of amount of absorption,*[1] *and comparative longitudinal and radial penetration.*

Species.	Character of wood.	Impregnation tests.	Penetrance tests.				Average dry weight per cubic foot.
			Average time of treatment.	Time required to penetrate 24 inches.	Average longitudinal penetration.	Average radial penetration.	
		Lbs. per cu. ft.	*Minutes.*	*Minutes.*	*Inches.*	*Inches.*	*Pounds.*
1. Red gum	Heartwood	2.03	70		1.35	0.09	38.8
2. White oak	do	3.40	70		2.32	.08	45.3
3. Red-heart beech	do	5.39	70		.50	.05	40.8
4. Bur oak	do	5.57	70		.61	.05	40.8
5. Rock elm	do	7.18	70	2 to 5	7.66	.33	38.6
6. Chestnut	do	7.32	70		4.00	.18	25.4
7. Sycamore	do	8.48	70		4.17	.23	35.0
8. Hackberry	do	8.54	70		10.83	.33	38.2
9. Hickory, mockernut.	do	9.86	70		6.06	.38	52.3
10. Sugar maple	do	10.09	45		5.33	.20	43.7
11. Hackberry	Sapwood	11.61	75	1	8.16	.45	35.8
12. Chestnut oak [2]	Heartwood	12.19					47.8
13. Red oak [2]	do	12.83					39.7
14. White-heart beech.	do	14.92	70		18.80	.24	43.0
15. Yellow birch	do	15.20	70	Immediately	10.39	.30	44.3
16. Red birch	do	15.46	70	25 to 35	8.36	.27	39.2
17. Black willow	do	16.24	70		4.87	(3)	29.0
18. Largetooth aspen.	do	16.28	70	45	6.23	.25	27.8
19. White elm	do	16.29	70		8.84	.43	34.2
20. Green ash	do	17.27	70	Immediately	10.61	.45	38.3
21. Slippery elm [2]	do	17.85					27.3
22. Silver maple	do	17.97	70		3.52	.30	36.0
23. Sweet birch	do	18.20	70	(4)	3.85	.30	46.9
24. Red gum	Sapwood	18.33	70		12.96	.33	36.7
25. White ash	Heartwood	18.83	70	4 to 7	8.16	.46	34.3
26. Silver maple	Sapwood	19.78	70	30 to 60	11.17	(3)	32.8
27. Basswood	Heartwood	20.36	70	7 to 12	12.11	.30	31.0
28. Tupelo gum	do	20.90	70	20	9.91	(3)	34.8
29. Wild red cherry	do	25.09	70		10.72	(3)	23.7
30. Tupelo gum	Sapwood	25.21	45	22 to 25	12.33	(3)	33.5

[1] The absorption tests were made in the treating cylinder and in most cases better penetrations were obtained in the species which took the higher absorptions. The pressures and times used in these tests are not comparable to commercial conditions.

[2] Not treated in the penetrance apparatus on account of the open condition of the pores. A good penetration was secured in tests made in the treating cylinder.

[3] Complete. Since the radial penetration of tupelo gum, wild red cherry, black willow, and silver maple was complete the relative order of those species is not important.

[4] Specimens were not straight grained, and oil passed out at the side.

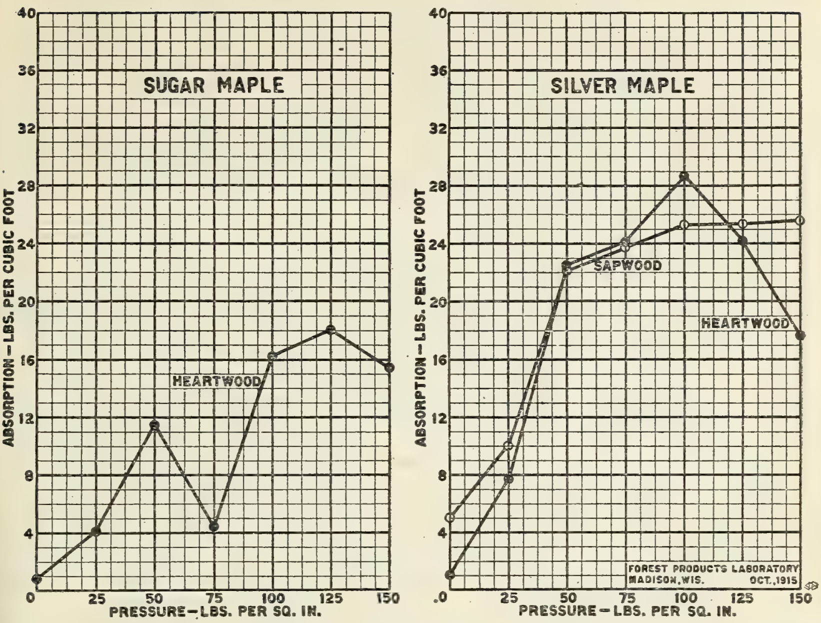

FIG. 14.—Absorption in the heartwood of sugar maple and silver maple and the sapwood of silver maple.

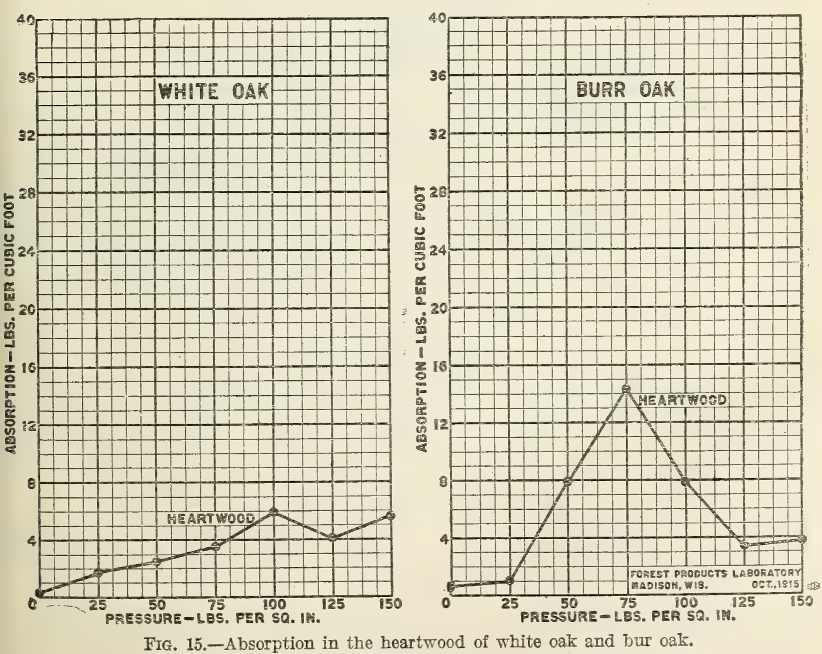

FIG. 15.—Absorption in the heartwood of white oak and bur oak.

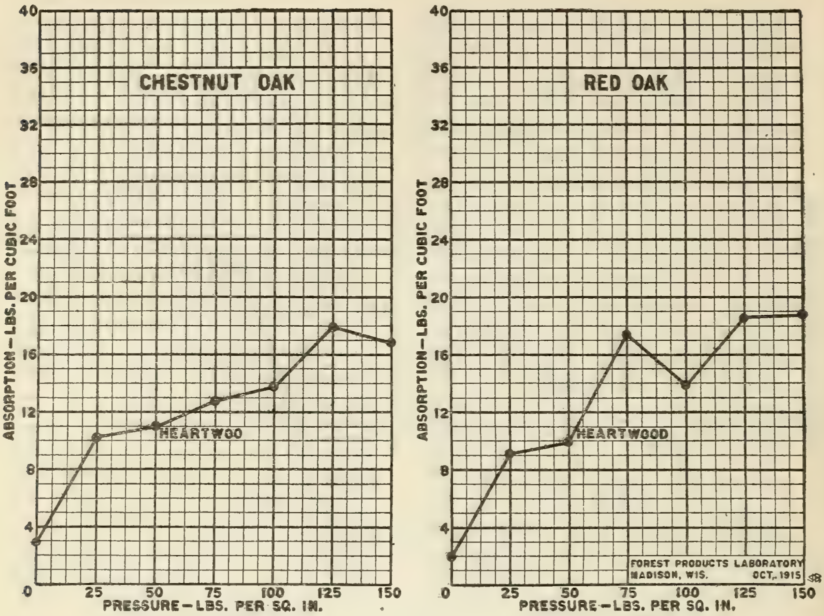

FIG. 16.—Absorption in the heartwood of chestnut oak and red oak.

TABLE 3.—*Results of penetrance tests on individual pieces.*

ROCK ELM—HEARTWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven dry weight per cubic feet.	Time of treatment.	Time required to penetrate 24 inches.[1] First end.	Time required to penetrate 24 inches.[1] Second end.	Penetrations. Average longitudinal.	Radial. Average.	Radial. Maximum.	Tangential. Average.	Tangential. Maximum.
	Per ct.		*Pounds.*	*Hours.*	*Min.*	*Min.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
48	6.1	14	38.40	½	2	3	5.83	0.20	0.30	0.25	0.30
49	2.0	16	37.20	1	½	1	11.65	.40	.50	.30	.60
50		14	39.80	2	2	5	5.50	.40	.50	.40	.60
Average							7.66	.33	.43	.32	.50
RED BIRCH—HEARTWOOD.											
51	12.0	18	39.60	½			8.50	0.30	0.35	0.30	0.40
52	9.7	14	39.30	1	35		8.17	.25	.30	.25	.30
53	6.5	13	38.50	2	25		8.43	.25	.35	.30	.40
Average							8.37	.27	.33	.28	.37
SWEET BIRCH [2]—HEARTWOOD.											
57		20	47.10	½			4.17	0.30	0.35	0.25	0.30
58		21	47.12	1			3.83	.40	.50	.40	.50
59	12.2	18	44.62	2			3.56	.25	.25	.25	.30
Average							3.85	.32	.37	.30	.37

[1] These periods are not comparable to those obtained in commercial treating plants.
[2] Specimens were crooked grain. Oil passed out at side instead of following to end, as it would have done in straight-grained wood.

Table 3.—*Results of penetrance tests on individual pieces*—Continued.

Piece No.	Moisture.	Average number of rings per inch.	Oven dry weight per cubic feet.	Time of treatment.	Time required to penetrate 24 inches.		Penetrations.				
					First end.	Second end.	Average longitudinal.	Radial.		Tangential.	
								Average.	Maximum.	Average.	Maximum.
	Per ct.		*Pounds.*	*Hours.*	*Min.*	*Min.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
CHESTNUT—HEARTWOOD.											
60		12	24.00	½			2.96	0.15	0.20	0.20	0.20
61	6.2	13	28.80	1			5.14	.20	.30	.20	.30
62	6.0	13	26.35	2			3.89	.20	.25	.15	.20
Average							4.00	.18	.25	.18	.23
WHITE ASH—HEARTWOOD.											
66	5.0	20	35.50	½	7	7	4.81	0.35	0.50	0.25	0.30
67		16	34.70	1	4		8.84	.50	.60	.50	.60
68	10.6	19	32.85	2			10.83	.52	.60	.45	.50
Average							8.16	.46	.57	.40	.47
HICKORY—HEARTWOOD.											
69	2.9	4	51.60	½			4.50	0.25	0.30	0.30	0.40
70		5	52.50	1			4.83	.30	.40	.25	.30
71		4	52.20	2			8.84	.60	.75	.60	.70
Average							6.06	.38	.48	.38	.47
YELLOW BIRCH—HEARTWOOD.											
30	2.4	12	46.00	½	Immediately.		8.17	0.30	0.30	0.35	0.40
31		14	44.50	1	Do.		10.83	.30	.35	.30	.40
32	7.0	16	42.30	2	Do.		12.16	.25	.30	.30	.45
Average							10.39	.28	.32	.32	.42
SILVER MAPLE—HEARTWOOD.											
33		12	36.24	½			3.50	0.20	0.30	0.30	0.40
34		13	35.70	1			3.56	.30	.40	.40	.60
35		11	36.20	2			3.50	.40	.50	.40	.60
Average							3.52	.30	.40	.37	.53
SILVER MAPLE—SAPWOOD.											
36	4.4	10	32.40	½			7.17	Complete			
37		10	33.17	1	30		14.84	do.[1]			
38		7		2	60		11.50	do.			
Average							11.17				
BASSWOOD—HEARTWOOD.											
39		22	30.30	½			7.00	0.30	0.45	0.30	0.50
40	12.3	20	29.60	1	12	12	14.84	.20	.20	.25	.30
41		18	31.90	2	7	7	14.50	.45	.50	.40	.40
Average							12.11	.32	.38	.32	.40

[1] Complete radial penetration was at least three-fourths inch. Where part of specimens showed complete radial penetration they were not included in the average.

TABLE 3.—*Results of penetrance tests on individual pieces*—Continued.

Piece No.	Moisture.	Average number of rings per inch.	Oven dry weight per cubic feet.	Time of treatment.	Time required to penetrate 24 inches.		Penetrations.				
					First end.	Second end.	Average longitudinal.	Radial.		Tangential.	
								Average.	Maximum.	Average.	Maximum.
	Per ct.		*Pounds.*	*Hours.*	*Min.*	*Min.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
SYCAMORE—HEARTWOOD.											
42	5.2	32	35.60	½			3.83	0.20	0.30	0.20	0.30
43	0.1	32	34.40	1			2.94	.30	.40	.30	.30
44	1.0	30	35.50	2			5.75	.20	.30	.20	.30
Average							4.17	.23	.33	.23	.30
LARGETOOTH ASPEN—HEARTWOOD.											
45			27.63	½			5.21	0.30	0.40	0.50	0.70
46	2.4		27.15	1	45		11.83	Complete [1]			
47	2.2		28.40	2			1.64	.20	.30	.25	.40
Average							6.23	.25	.35	.38	.55
WHITE ELM—HEARTWOOD.											
1	1.8	16	29.58	½			8.17	0.50	0.70	0.60	0.70
2	10.5	13	30.61	1			4.17	.40	.50	.50	.60
3	4.8	12	30.71	2			14.18	.40	.60	.60	.60
Average							8.84	.43	.60	.57	.63
GREEN ASH—HEARTWOOD.											
9	11.2	12	39.30	½	Immediately		8.84	0.40	0.45	0.40	0.50
10	11.0	14	36.50	1	do		9.50	.50	.60	.50	.60
11	.9	13	40.10	2	do		13.50	Complete [1]			
Average							10.61	.45	.52	.45	55
HACKBERRY—HEARTWOOD.											
12		8	36.70	½			6.16	0.30	0.40	0.40	0.50
13		10	36.30	1			14.84	.40	.50	.40	.50
14		10	41.70	2			11.50	.30	.40	.30	.40
Average							10.83	.33	.43	.37	.47
HACKBERRY—SAPWOOD.											
15	1.5	8	35.20	½			6.16	0.50	0.70	0.60	0.70
17	6.0	10	36.40	2	1		10.16	.40	.50	.40	.50
Average							8.16	.45	.60	.50	.60
BUR OAK—HEARTWOOD.											
18	8.3	15	40.70	½			0.83	0.05	0.05		
19	8.1	15	41.56	1			.50	.05	.05		
20	12.3	16	41.10	2			.50	.05	.05		
Average							.61	.05	.05		

[1] Complete radial penetration was at least three-fourths inch. Where parts of specimens showed complete radial penetration they were not included in the average.

TABLE 3.—*Results of penetrance tests on individual pieces*—Continued.

Piece No.	Moisture.	Average number of rings per inch.	Oven dry weight per cubic feet.	Time of treatment.	Time required to penetrate 24 inches. First end.	Time required to penetrate 24 inches. Second end.	Penetrations. Average longitudinal.	Penetrations. Radial. Average.	Penetrations. Radial. Maximum.	Penetrations. Tangential. Average.	Penetrations. Tangential. Maximum.
	Per ct.		*Pounds.*	*Hours.*	*Min.*	*Min.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
TUPELO GUM—HEARTWOOD.											
24		11	36.45	½			10.83	Complete[1]			
25	19.5	10	32.20	1			8.08				
26		12	35.07	2	20		10.83				
Average							9.91				
TUPELO GUM—SAPWOOD.											
27	3.0	15	31.40	½	20	22	8.17	Complete[1]			
28	0.5	14	32.53	1	22	20	16.50	do.			
Average							12.33				
BLACK WILLOW—HEARTWOOD.											
71	0.6	4	29.05	½			4.83	0.25	0.30	0.30	0.40
72	1.8	4	29.09	1			6.28	Complete[1]			
73		4	28.62	2			3.50	do.			
Average							4.87				
SUGAR MAPLE—HEARTWOOD.											
74	3.2	22	43.75	½			3.83	0.15	0.20	0.20	0.30
75	8.5	18	43.15	1			6.84	.25	.30	.20	.32
Average							5.33	.20	.25	.20	.31
WHITE OAK—HEARTWOOD.											
77		16		½			1.50	0.07	0.1		
78		17		1			2.62	.07	0.1		
79		16		2			2.83	.10	0.1		
Average							2.32	.08	0.1		
RED GUM—HEARTWOOD.											
80	8.0		40.12	½			1.28	0.07	0.10	0.10	0.20
81			38.63	1			1.50	.15	.02	.08	.15
82	15.2		38.32	2			1.28	.05	.05	.10	.10
Average							1.35	.09	.12	.09	.15
RED GUM—SAPWOOD.											
54		14	38.58	½	3	8	16.16	0.35	0.40	0.40	0.50
55	1.8	14	35.70	1	1	3	10.21	Complete[1]			
56		16	35.70	2	2	10	12.50	.30	.50	.40	.60
Average							12.96	.32	.45	.40	.55

[1] Complete radial penetration was at least three-fourths inch. Where part of specimens showed complete radial penetration they were not included in the average.

TABLE 3.—*Results of penetrance tests on individual pieces*—Continued.

WHITE HEART BEECH.

Piece No.	Moisture.	Average number of rings per inch.	Oven dry weight per cubic feet.	Time of treatment.	Time required to penetrate 24 inches.		Penetrations.				
					First end.	Second end.	Average longitudinal.	Radial.		Tangential.	
								Average.	Maximum.	Average.	Maximum.
	Per ct.		*Pounds.*	*Hours.*	*Min.*	*Min.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
86	6.7	8	43.20	½			14.8	0.18	0.25	0.20	0.30
87	7.6	7	42.80	1			18.1	.30	.40	.30	.40
88		8		2			23.5	Complete [1]			
Average							18.8	.24	.32	.25	.35

RED HEART BEECH.

Piece No.	Moisture.	Average number of rings per inch.	Oven dry weight per cubic feet.	Time of treatment.	First end.	Second end.	Average longitudinal.	Radial average.	Radial maximum.	Tangential average.	Tangential maximum.
89	9.0	17	41.00	½			0.50	0.05	0.05		
90	8.9	16	40.60	1			.43	.05	.05		
91		15		2			.57	.05	.05		
Average							.50	.05	.05		

WILD RED CHERRY—HEARTWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven dry weight per cubic feet.	Time of treatment.	First end.	Second end.	Average longitudinal.	Radial average.	Radial maximum.	Tangential average.	Tangential maximum.
83		6	23.82	½			8.17	Complete [1]			
84	3.5	5	23.50	1			12.50	do			
85		6		2			11.50	do			
Average							10.72				

[1] Complete radial penetration was at least three-fourths inch. Where part of specimens showed complete radial penetration they were not included in the average.

BIBLIOGRAPHY.

DEPARTMENTAL PUBLICATIONS.

Title.	Date of issue.
The Decay of Timber and Methods of Preventing It. Bureau of Plant Industry Bulletin 14	1902
Seasoning of Timber. Forest Service Bulletin 41	1903
Cross Tie Forms and Rail Fastenings with Special Reference to Treated Timbers. Forest Service Bulletin 50	1904
Report on Condition of Treated Timbers Laid in Texas, February, 1902. Forest Service Bulletin 51	1904
Wood Preservation in the United States. Forest Service Bulletin 78	1909
The Fractional Distillation of Coal Tar Creosote. Forest Service Circular 80	1907
Quantity and Character of Creosote in Well Preserved Timbers. Forest Service Circular 98	1907
The Open Tank Method for the Treatment of Timber. Forest Service Circular 101	1907
Brush and Tank Pole Treatments. Forest Service Circular 104	1907
Prolonging the Life of Mine Timbers. Forest Service Circular 111	1907
The Analysis and Grading of Creosotes. Forest Service Circular 112	1908
The Preservative Treatment of Fence Posts. Forest Service Circular 117	1907
Preservation of Piling against Marine Wood Borers. Forest Service Circular 128	1908
Experiments on the Strength of Treated Timber. (Second edition.) Forest Service Circular 39	1908

BIBLIOGRAPHY—Continued.

DEPARTMENTAL PUBLICATIONS—Continued.

Title.	Date of issue.
Holding Force of Railroad Spikes in Wooden Ties. Forest Service Circular 46	1908
Wood Paving in the United States. Forest Service Circular 141	1908
The Seasoning and Preservative Treatment of Hemlock and Tamarack Cross Ties. Forest Service Circular 132	1908
The Estimation of Moisture in Creosoted Wood. Forest Service Circular 134	1908
A Primer of Wood Preservation. Forest Service Circular 139	1908
Experiments with Railway Cross Ties. Forest Service Circular 146	1908
Consumption of Wood Preservatives and Quantity of Wood Treated in 1910. Forest Service Circular 186	1911
Preservative Treatment of Loblolly Pine Cross Arms. Forest Service Circular 151	1908
Preservative Treatment of Poles. Forest Service Bulletin 84	1911
Volatilization of Various Fractions of Creosote after Their Injection into Wood. Forest Service Circular 188	1911
Modification of Sulphonation Test for Creosote. Forest Service Circular 191	1911
Prevention of Sap Stain in Lumber. Forest Service Circular 192	1912
Progress Report on Wood Paving Experiments in Minneapolis. Forest Service Circular 194	1912
Quantity and Quality of Creosote Found in Two Treated Piles after Long Service. Forest Service Circular 199	1912
The Preservation of Mine Timbers. Forest Service Bulletin 107	1912
Commercial Creosotes. Forest Service Circular 206	1912
The Absorption of Creosote by the Cell Walls of Wood. Forest Service Circular 200	1912
Condition of Experimental Chestnut Poles in the Warren-Buffalo and Poughkeepsie-Newton Square Lines after Five and Eight Years' Service. Forest Service Circular 198	1912
Prolonging the Life of Cross Ties. Forest Service Bulletin 118	1912
Service Tests of Ties. Forest Service Circular 209	1912
Experiments in the Preservative Treatment of Red Oak and Hard Maple Cross Ties. Forest Service Bulletin 126	1913
Tests of Wood Preservatives. Department of Agriculture Bulletin 145	1915
Relative Resistance of Various Conifers to Injection with Creosote. Department of Agriculture Bulletin 101	1914
The Toxicity to Fungi of Various Oils and Salts. Department of Agriculture Bulletin 227	1915
The Preservative Treatment of Farm Timbers. Farmers' Bulletin 744	1916

PAPERS PREPARED BY FOREST PRODUCTS LABORATORY AND PUBLISHED IN PROCEEDINGS OF SOCIETIES, AND TECHNICAL, TRADE, AND OTHER JOURNALS.

Title.	Author.	Where published.	Date.
The Preservation of Structural Timbers from Decay.	Winslow, C. P.	Proc. Eng. Soc. Western Pa., vol. 26, No. 9, pp. 427-451.	Dec., 1910.
Structure of Commercial Woods in Relation to the Injection of Preservatives.	Weiss, H. F.	Proc. Am. Wood Preservers' Assn. pp. 159-187.	1912.
Some Tests to Determine the Effect upon Absorption and Penetration of Mixing Tar with Creosote.	Bond, F. M.	Proc. Am. Wood Preservers' Assn. pp. 216-274.	1913.

BIBLIOGRAPHY—Continued.

PAPERS PREPARED BY FOREST PRODUCTS LABORATORY AND PUBLISHED IN PROCEEDINGS OF SOCIETIES, AND TECHNICAL, TRADE, AND OTHER JOURNALS—Continued.

Title.	Author.	Where published.	Date.
Efficiency of Various Parts of Coal-tar creosote against Marine Borers.	Teesdale, C. H.	Engineering Rec.	Sept. 12, 1914.
Bleeding and Swelling of Paving Blocks.	do	Proc. Am. Wood Preservers' Assn. pp. 372–397.	1915.
History of Treated Wood Block Pavements in the United States.	do	Proc. Am. Wood Preservers' Assn. pp. 324–367.	Do.
Temperature Changes in Wood under Treatment.	Hunt, George M.	Proc. Am. Wood Preservers' Assn. pp. 85–100.	Do.
Preservative Treatment of Timber.	Weiss, H. F., Teesdale, C. H.	International Eng. Congress.	Do.
Method of Determining the Amount of $ZnCl_2$ in Treated Wood.	Bateman, E.	Jour. Ind. and Eng. Chemistry.	Jan., 1914
The Effect of Varying the Preliminary Air Pressure in Treating Ties upon the Absorption and Penetration of Creosote.	Teesdale, C. H.	Proc. Am. Wood Preservers' Assn. pp. 323–351.	1914.
Air Seasoning of Timber.	Kempfer, W. H.	Am. Ry. Eng. Assn. Bulletin 161.	Nov., 1913.
		Am. Ry. Eng. Assn. Proc., Ry. Review, part 2, pp. 163–232.	Jan. 10, 1914.
The Protection of Ties from Mechanical Destruction.	Weiss, H. F.	Proc. Am. Wood Preservers' Assn. pp. 249–260.	1914.
Tests on the Inflammability of Untreated Wood and of Wood Treated with Fire-Retarding Compounds.	Prince, R. E.	Proc. National Fire Protection Assn. pp. 108–157.	1915.
Some Factors Affecting the Application of Wood Preservation to Electric Railways.	Winslow, C. P., C. H. Teesdale.	Proc. Am. Elec. Ry. Eng. Assn.	Oct., 1915.
The Application of the Davis Spot Test in the Preliminary Examination of Creosotes.	Cloukey, H.	Jour. Ind. and Eng. Chemistry.	Nov., 1915.
Treated Wood Block for Factory Floors.	Teesdale, C. H.	Proc. of Am. Wood Preservers' Assn.	Jan., 1916.
The Use of Sodium Fluoride in Wood Preservation.	do	Wood Preserving	Oct.-Dec. 1916 Jan.-Mar. 1917
Tie Durability Records.	Winslow, C. P., C. H. Teesdale.	Proc. Am. Ry. Eng. Assn. p. 463.	Mar., 1916.
Tie Durability Records.	P. R. Hicks.	Proc. Am. Ry. Eng. Assn. p. 1291.	Mar., 1917.
Effect of Treatment on Strength of Paving Blocks.	C. H. Teesdale, J. A. Newlin.	Proc. Am. Wood Preservers' Assn. p. 462.	Jan., 1917.